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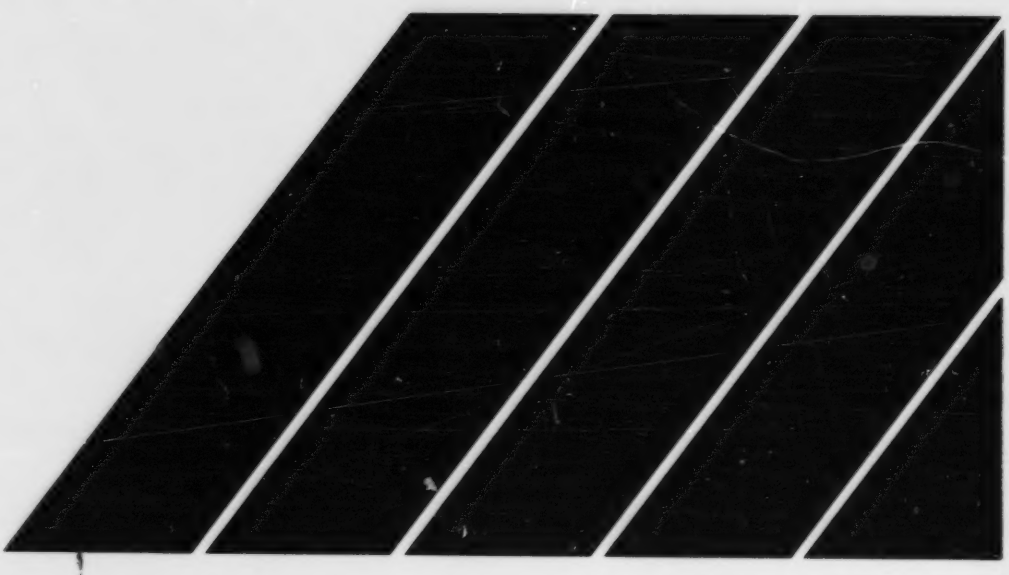
Direction de la technologie de l'efficacité énergétique et des énergies de remplacement

OPERATING CHARACTERISTICS AND PERFORMANCE OF THE AERECO HUMIDITY-CONTROLLED VENTILATION SYSTEM, PHASE II: MONITORING AND PERFORMANCE ANALYSIS



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91-04784/

OPERATING CHARACTERISTICS AND PERFORMANCE OF THE AERECO HUMIDITY-CONTROLLED VENTILATION SYSTEM, PHASE II: MONITORING AND PERFORMANCE ANALYSIS

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
DSS Contract No. 03SQ.23216-6-6324/07
December, 1990

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109 pp

MICROMEDIA

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CITATION

Parekh, A., K. Ruest and Y. Lemoine, Scanada Consultants Ltd. Operating Characteristics and Performance of the AERECO Humidity-Controlled Ventilation System, Phase II: Monitoring and Performance Analysis. DSS Contract No. 03SQ.23216-6-6324/07. Efficiency and Alternative Energy Technology Branch, Energy, Mines and Resources Canada, Ottawa, Ontario. 1990 (98 pp.)

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NOTE

Funding for this project was provided by the Federal Panel on Energy Research and Development, Energy, Mines and Resources Canada.

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Catalogue No. M91-7/142-1991E
ISBN. 0-662-18841-1

ACKNOWLEDGEMENT

The "*Operating Characteristics and Performance of the AERECO Humidity-Controlled Ventilation System - Phase II: Monitoring and Performance Analysis*" project was conducted for Energy, Mines and Resources Canada. The research, technical analysis and field work was performed by Scanada Consultants Limited.

Mark Riley of Energy, Mines and Resources Canada developed the scope of work, supervised its execution, and thoroughly reviewed all stages of this project.

Laurent Jardinier and Pascal Teigne of CAN-AERECO Ventilation Inc. were responsible for material supply and installation of AERECO Humidity-Controlled Ventilation System in two houses. John Gusdorf of Sciemetric installed and debugged the monitoring system.

We would like to thank the home-owners Mr. and Mrs. Gauthier of Carleton Place and Mr. and Mrs. Wheeler of Morewood for allowing us to install and monitor the ventilation system. We sincerely appreciate their patience and participation in this valuable project.

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EXECUTIVE SUMMARY

AERECO humidity-controlled ventilation systems rely on humidity levels generated by the occupants as being the controlling variable determining the necessary ventilation rate. In this way it attempts to follow a "demand-controlled ventilation" strategy (DCV): ventilate the house when and as needed.

The main objective of this project is to assess and evaluate the AERECO ventilation system regarding its operating and performance characteristics, and particularly its ventilation effectiveness in typical Canadian houses. The field monitoring program was designed to gauge how well the ventilation system and the house respond to changes in indoor humidity. The system was installed in two single storey detached houses located near Ottawa, Ontario. These houses were monitored during the winter months of December 1989 to April 1990. Various operating parameters such as relative humidity, temperature, indoor/outdoor pressure difference, extractor flows, air inlet response, ambient conditions and energy consumption were continuously monitored using a computerized data acquisition system. Frequent field visits were made to ensure proper functioning of the system and the monitoring equipment.

The change in relative humidity due to occupancy is sensed by the air inlet, which responds to vary the fresh air supply. During normal occupancy, in most cases, relative humidity changes by 1 to 10%. The difference in estimated air flow due to such changes in RH, through the individual air inlet, varied from 0.8 L/s to a maximum of 1.7 L/s. The relative humidity levels did not appear to reflect the levels of normal human activity in any significant way during normal occupancy. However, AERECO air inlets (in its current configuration) showed quick response to sudden changes in occupancy (surge loads), increasing the air flow from 0.8 to 3.5 L/s in such surge load cases.

Carbon dioxide levels do appear to track human presence and levels of activity very well. A rise in CO_2 occurs consistently at times of maximum activity. CO_2 appears to be a good indicator of occupancy and indoor air quality in demand-controlled ventilation systems. With AERECO there is only a weak correlation between the occupancy (CO_2) and the response of air inlets. In both houses, the CO_2 levels in the master bedroom peaked at more than 1200 ppm and remained above this level for a period of three to seven hours during the night. It is probable, therefore, that the current air inlet system is not providing adequate fresh air supply. Since CO_2 appears to be a good indicator of occupancy, the demand-controlled ventilation systems, like AERECO, might require a combination of CO_2 and indoor relative humidity sensors to provide good air quality and moisture control in Canadian houses.

The in-flow and out-flow calculations showed the following results for both houses: The fresh air flow through air inlets varied from a minimum of 12% during non occupancy periods to a maximum of 27% of the total air flow during full occupancy. Estimated total air flow though all air inlets varied from 6.5 L/s to 16 L/s. Air leakage through the house envelope remained as the predominant component of fresh air supply. In this regard, the air inlets are of questionable value except where the air leakage patterns are uneven and

require additional leakage in specific applications.

The performance analysis of the exhaust system showed that continuous air exhaust was maintained adequately by the extractors. The flow measurements showed that these units were working according to their settings and on an average provided 47 L/s of exhaust in both houses. The total extractor flow varied from 18 L/s during unoccupied periods to 65 L/s during peak activities. These extractors kept the house depressurized by 3 to 7 Pa.

Energy efficiency is achieved with a DCV system by cutting back the fresh air provided to house occupants, ideally at times when it is not required by the house occupants. The results of air quality monitoring (CO_2) in both houses, however, raise questions about the suitability of humidity sensing as an exclusive demand control strategy for ventilation.

The AERECO system was effective in controlling condensation on windows in the house; however, the components need improvements to meet the minimum ventilation requirements as specified by the CSA Standard F326.

SOMMAIRE

Les systèmes de ventilation AERECO sont contrôlés par le niveau d'humidité généré par les occupants, la variable de contrôle qui détermine le débit de ventilation requis. Les concepteurs ont tenté de soumettre ces systèmes à une stratégie de ventilation contrôlée par la demande pour ne ventiler une maison qu'au besoin.

Le principal objectif de ce projet était d'évaluer les caractéristiques de fonctionnement et de rendement du système de ventilation AERECO, particulèrement en termes d'efficacité dans une maison canadienne type.

Un programme de monitorage sur le terrain a été conçu pour évaluer à quel point le système de ventilation et la maison répondent bien à des changements d'humidité intérieure. Le système AERECO a été installé dans deux maisons unifamiliales d'un étage situées près d'Ottawa (Ontario). Les maisons ont été contrôlés d'avril 1989 à décembre 1990. Divers paramètres de fonctionnement, dont l'humidité relative, la température, la différence de pression entre l'intérieur et l'extérieur, les débits d'évacuation, la réponse de la prise d'air, les conditions ambiantes et la consommation d'énergie, ont été contrôlés en continu au moyen d'un système informatisé de saisie des données. Des visites fréquentes ont été faites sur le terrain pour s'assurer du bon fonctionnement du système de ventilation et du matériel de monitorage.

Le changement d'humidité relative en présence d'occupants est décelé par la prise d'air qui répond en variant l'alimentation en air frais. Le plus souvent pendant une occupation normale, l'humidité relative varie de un à dix pour cent. Le débit estimé dans les prises d'air a varié en fonction des changements d'humidité relative entre 0,8 et un maximum de 1,7 L/s. En cours d'occupation normale, l'humidité relative n'a pas semblé refléter le niveau d'activité humaine normale d'une manière manifeste. Cependant, dans leur configuration actuelle, les prises d'air du système AERECO ont présenté une réponse rapide à des changements soudains d'occupation, augmentant le débit d'air de 0,8 à 3,5 L/s pendant les charges de pointe.

Les niveaux de dioxyde de carbone (CO_2) semblent refléter très fidèlement la présence et l'activité humaines. Il y a toujours une élévation du niveau de CO_2 lorsque l'activité est maximale. Le CO_2 semble être un bon indicateur d'occupation et de qualité de l'air intérieur dans les systèmes de ventilation contrôlés par la demande. Cependant, dans le système AERECO, la corrélation

est faible entre le niveau de CO_2 et la réponse des prises d'air. Dans les deux maisons, les niveaux de CO_2 dans la chambre des maîtres a atteint un maximum de plus de 1200 ppm pendant une période de trois à sept heures la nuit. Il est donc probable que le système de prises d'air actuel n'assure pas une alimentation suffisante en air frais. Comme le CO_2 semble être un bon indicateur de l'occupation, les systèmes de ventilation contrôlés par la demande comme le système AERECO devraient peut-être être munis de capteurs de CO_2 et d'humidité relative intérieure pour assurer une bonne qualité de l'air et bien contrôler l'humidité, dans les maisons canadiennes.

Les calculs des débits d'entrée et de sortie ont révélé les résultats suivants pour les deux maisons. Le débit d'air frais dans les prises d'air a varié entre un minimum de 12 pour cent pendant les période d'inoccupation et un maximum de 27 pour cent du débit d'air total pendant la période de pleine occupation. Le débit d'air total estimé dans toutes les prises d'air a varié de 6,5 à 16 L/s. Les fuites d'air à travers l'enveloppe de la maison sont demeurées la principale cause d'alimentation en air frais. Par conséquent, les prises d'air sont de valeur discutable, sauf là où les fuites d'air sont mal réparties et sont insuffisantes dans des applications particulières.

Une analyse du rendement du système d'évacuation a montré qu'une évacuation en continu de l'air était correctement entretenue par les évacuateurs. Les mesures de débit ont rélévé que ces appareils ont fonctionné conformément aux réglages et ont évacué 47 L/s en moyenne dans les deux maisons. Le débit total des évacuateurs a varié entre 18 L/s pendant les périodes de pointe. Ces évacuateurs ont maintenu les maisons à une pression relative négative de 3 à 7 Pa.

L'efficacité énergétique du système de ventilation contrôlé par la demande tient aux coupures de l'alimentation en air frais, idéalement lorsque les occupants de la maison n'en ont pas besoin. Cependant, les résultats du contrôle de la qualité de l'air dans les deux maisons soulèvent des questions quant à la pertinence de la détection de l'humidité comme stratégie exclusive de contrôle de la ventilation par la demande. Même si le système AERECO a bien contrôlé la condensation dans les fenêtres de la maison, ses composantes ont besoin d'être améliorées pour satisfaire les exigences de ventilation minimales de la norme CSA F326.

1. INTRODUCTION

Canadian housing has evolved a great deal in the last 20 years. Modern houses have significantly improved building envelopes in terms of insulation and airtightness. Construction methods have improved and many new construction materials are being used. These changes were mostly driven by the desire to improve energy efficiency and comfort in buildings.

Given the current trend towards increased airtightness of house envelopes, it is recognized that houses now being built in North America will have to incorporate some form of controlled mechanical or passive ventilation. The "natural ventilation" offered by accidental air-leakage is arguably inadequate to ensure acceptable air quality. The controlled ventilation assists in removing the moisture source as well as providing sufficient fresh air to occupants.

In Canada, the CSA Standard F326 - *Residential Mechanical Ventilation Requirements* - defines the requirements for mechanical ventilation systems for providing minimum controlled rates of ventilation air to habitable spaces [CSA-F326 1989]. The ventilation and exhaust air requirements specified in this Standard are intended to deal with contaminants at the rate of generation normally encountered in residential dwellings. It is likely, although not certain, that the F326 Ventilation Standard will be referenced, as mandatory, in the 1995 National Building Code and in those provincial codes based on it. The house ventilation requirements can be met either by using continuous or intermittent air supply and exhaust devices. Table 1 shows the ventilation requirements. The minimum mechanical ventilation requirement is 0.3 air changes per hour (ach). These requirements are similar to ASHRAE Standard 62-1989 [ASHRAE 1989].

Ventilation equipment manufacturers are introducing new products to supply packaged ventilation systems to builders. One such ventilation product, manufactured by CAN-AERECO, is based on demand-controlled strategy -- house ventilation only when needed -- being field tested in Canada. The AERECO Humidity-Controlled Ventilation system provides the components of "passive" fresh air inlets and either continuous or intermittent mechanical air exhaust system. The AERECO system was developed in France and more than 135,000 of these systems have been installed to date in Europe.

The main purpose of this project is to assess and evaluate the AERECO ventilation system as a whole, and its components, to determine operating and performance characteristics in typical Canadian houses in cold climate. The AERECO demand controlled ventilation system is evaluated with the following assumptions:

- occupant related pollutants dominate building related pollutants; and
- the building envelope is sufficiently air-tight that some form of passive or mechanical ventilation is required.

Table 1: Minimum Residential Ventilation Air Requirements

Space Classification	Base Flow Rate L/s	Intermittent Exhaust Flow L/s	Continuous Exhaust Flow L/s
Category A			
Double / Master bedroom	10	-	-
Basement	10	-	-
Single bedrooms	5	-	-
Living room	5	-	-
Dining room	5	-	-
Family room	5	-	-
Recreation room	5	-	-
Other	5	-	-
Category B			
Kitchen	5	50	30
Bathroom	5	25	15
Laundry	5	-	-
Utility room	5	-	-

1.1 AERECO Humidity-Controlled Ventilation System

The AERECO Humidity-Controlled ventilation system was developed in France in response to a mechanical ventilation requirement incorporated into French building code in 1982. Approximately 135,000 of these systems have been installed to date in Europe. The AERECO system consists of three basic components: a continuously running central extractor fan, humidity-controlled air extractor units ducted to the central extractor fan, and humidity-controlled air inlet units. Appendix C contains the description of AERECO system and various components.

The AERECO ventilation is intended for the use in both new housing and for retrofit. It relies on the humidity levels at the air exhaust or intake units to determine the level of ventilation required. Air extractors, which are hooked to the central exhaust fan, are placed in rooms where humidity is produced such as bathrooms, kitchens and laundry rooms. The exhaust fan runs 24 hours a day at slow speed and continually maintains a slight negative pressure across the building envelope. The size of each extractor unit opening is determined by the indoor relative humidity levels at the extractor unit. For the air supply, air inlet units are installed in each occupied room where there are no extractor units. These are mounted 10 to 12 inches from the ceiling on an exterior wall and the size of each unit opening is determined by the indoor RH levels at the unit. AERECO claims various benefits: optimal supply of fresh air to occupants, elimination of condensation, energy savings by reducing the ventilation heat losses by more than 50%, automatic operation, and easy installation.

1.2 Scope and Objectives

The scope of this project is to monitor the AERECO Ventilation systems in two houses for establishing the performance characteristics and evaluating the suitability of AERECO ventilation systems in cold climates. The objectives here are to:

- monitor the operations of AERECO Ventilation System

- test various product / system characteristics and the operating performance, such as:
  - sensitivity to changes in relative humidity levels in outdoor and indoor air
  - influence on indoor air quality: continuous monitoring of CO_2, and frequent sampling of radon and formaldehyde levels
  - reaction time to respond to changes in humidity
  - response time and catch up time for "surge" loads, such as when several people enter room at the same time
  - influence of wind conditions and outdoor relative humidity on operation of inlet units
  - performance of inlet units during periods of extreme cold (i.e., stiffness of operation, slow to respond, freeze up..)
  - influence on the energy consumption (heating) in the dwelling
  - various measurements of air movements created by operation of the system: volumes, speeds, directions, stratification or mixing, and so on.

1.3 Report Organization

This report is organized as follows:

Section 2 presents the methods and general observations during the field monitoring. It also lists the various monitoring tasks and data collection points.

Section 3 presents the monitored results and performance analysis. Various trends in monitored parameters are noted and explained in physical behaviours.

Section 4 and 5 provides the discussion on AERECO ventilation system and concludes the outcome of long term winter monitoring of two houses.

Appendix A,B, and C provides the description of houses, monitoring system, and AERECO ventilation products.

Appendix D includes the manufacturer's response to the draft version of this report.

2. METHOD

During the first phase of this project, two houses were selected for installation and monitoring of AERECO ventilation system. These houses are located in eastern Ontario. These houses were first tested for airtightness and were sealed to obtained the air change rate lower than 3 air changes per hour (ac/h) at 50 Pa before installation of AERECO system. Comparison of airtightness results shows that these houses are relatively tighter than most new detached houses in Canada [Hamlin et. al. 1990]. The average air change rate (@ 50 Pa) of new detached housing stock is 3.4. The airtightness requirement for these two houses was verified by CAN-AERECO. After AERECO ventilation system was installed, the airtightness tests were done with air inlets full closed, full open and in physically sealed position. Appendix A provides house descriptions and airtightness results. The Phase I report describes these houses in detail [Scanada 1989].

The operation of AERECO ventilation system and the monitoring systems were explained to home owners. The ventilation system was made operational and was fully commissioned for a long term data collection in the last week of November 1989. Initially, the ventilation system was operated to debug and calibrate various measurements. The system was closely monitored for the first month of operation to verify the reliability and functioning of the equipment. As usual in field monitoring tasks, the synchronous operation of all data logging equipment took almost 3 to 4 weeks of debugging time. During the months of November and December, field trips were made at weekly intervals, or when called for, to physically inspect and check the ventilation and monitoring system. In the months of January, February, March and April visits were made every month, or when needed, to ensure continuous functioning of the monitoring system. The monitoring computers in these houses were connected with Scanada's main computers through modem. Data files were down loaded through modem every week from Carleton Place and Morewood.

2.1 House Description and Characteristics

The test houses are designated as Morewood House (House A) and Carleton Place House (House B). These houses take their label from the small communities where they are located. Both are factory-built homes built by Morewood Industries, Morewood, Ontario. Both houses are electrically heated with baseboard heaters controlled by individual wall mounted thermostats.

Morewood House (House A): This house is a split entrance, raised bungalow with three bedrooms, a dining room, living room, and kitchen as shown in Appendix A. The basement is unfinished, and as per the owner, would remain so. The electric baseboard heaters are controlled by individual wall mounted thermostats. This house has 109.7 m^2 (1,137 ft^2) of heated floor space and volume of 460.2 m^3. The estimated airflow to cause at 10 Pa pressure difference is 88.3 L/s.

Carleton Place House (House B): This house a three bedroom bungalow with eat-in kitchen, and living room as shown in Appendix A. It has a floor area of 101.8 m^2 (1,056 ft^2) and volume of 414.9 m^3. The estimated airflow to cause at 10 Pa pressure difference is 84.1 L/s. The basement is partially finished

with a walkout through sliding patio door to the side yard. As per the owner, the basement will remain partially finished until summer of 1990. The electric baseboard heaters with wall mounted thermostats are located in each room and wherever necessary. In the basement, in addition to electric base board heaters, there is also a wood burning stove with an exterior mounted metal chimney. Before monitoring of this house began in November 1989, the home owner was requested not to use the wood stove and keep the flue sealed for the duration of the monitoring period. However, the monitoring data showed that the wood stove was used during some periods in December, January and February. The performance analysis presented in this report does not include periods when the wood stove was used.

Before installing the AERECO ventilation system, the Carleton Place and Morewood houses were thoroughly inspected and sealed for the obvious cracks and leaks. Monthly billing data and general house characteristics were gathered. The AERECO ventilation system was installed by experienced HVAC contractors under the close supervision of CAN-AERECO and Scanada. The monitoring system and micro-computer based data collection system was installed by Scanada and Sciemetric.

Once the installation of the AERECO system and the monitoring equipment was complete, a series of house depressurization tests conforming to CGSB Standard 149.10-M86 were performed to see the effect of installation had on air-tightness of these houses. The depressurization tests were performed with the ventilation system turned off and the exhaust points sealed. Three tests were performed at each house. The first test to determine the air-tightness with air inlets sealed, the second with the inlets at minimum position, and the third with the inlets at maximum position. Table 2 summarizes the results of these tests. Appendix A provides the detailed house description and airtightness results.

2.2 Ventilation System

The ventilation system, in the above mentioned houses, consists of a central 100 L/s (200 cfm) exhaust fan running at a constant static pressure of 100 Pa. The exhaust fan is ducted to "extractor units" each located in kitchen, bathroom and the laundry room. There are three extractor units in House A: in the kitchen, bathroom, and basement near laundry area. In House B there are four extractor units: in the kitchen, bathroom, laundry area and workshop.

Extractor Units:

The extractor units are used to control the rate of exhaust by automatically varying the size of the extractor opening in proportion to the level of indoor relative humidity (RH). The extractor opening contains an inflatable rubber tube/spring assembly, which controls the dimension of the opening pneumatically. As the relative humidity in the space rises, the pneumatic circuit closes, causing the tube to lengthen and allowing greater air flow through the extractor. As the relative humidity drops, the tube shortens and widens, reducing air flow through the extractor. In this way, the exhaust rate is proportioned according to the relative humidity.

The extractor units can be adjusted to operate over two humidity ranges: a "low altitude" or moderate

climate range, and a "high altitude" or cold climate range. The low altitude range is 40% to 75%, and the "high altitude" is 25% to 60% RH. Consequently, a large extractor unit will automatically adjust its flow to a maximum of 30 cfm whenever the RH exceeds 75% in low altitudes. At higher altitudes, the maximum would be achieved at an RH of 60%. The "altitude" settings can be used to customize the installation to the local climate, to lifestyle, or to other factors which may affect desired RH and ventilation rates [Baets and Dietz 1986].

Table 2: Airtightness Test Results

Test	E.L.A. cm^2	N.L.A. cm^2/m^2	Q @ 10 Pa L/s	Q @ 50 Pa L/s	ACPH @ 50 Pa
Morewood House					
House A					
Inlets Sealed	354.6	0.91	88.3	332.1	2.60
Inlets - minimum position	422.4	1.08	105.2	362.2	2.83
Inlets - maximum position	512.2	1.31	127.5	405.9	3.18
Carleton Place House					
House B					
Inlets Sealed	337.8	0.96	84.1	268.2	2.33
Inlets - minimum open position	379.3	1.08	94.4	305.9	2.66
Inlets - maximum open position	427.3	1.21	106.4	349.1	3.03

Air Inlets

The humidity-controlled air inlet is the component of the AERECO ventilation system designed to distribute the incoming fresh air in each room according to respective relative humidity prevailing in the room.

The AERECO air inlets are installed with through-the-wall supply diffusers, placed in each bedroom and the main living area in the house. The air flow into the house through the supply diffusers is controlled by the relative humidity of each room or space. The humidity-controlled air inlet allows to change the opening section from 5 cm^2 to 30 cm^2 according to the humidity level in the room. The air inlets have two positions: with the position signed (●), the opening section is 5 cm^2 for 40% humidity and 30 cm^2 for 75% humidity; with the position signed (+), the opening section is 5 cm^2 for 25% humidity and 30 cm^2 for 60% humidity. Table 3 summarizes the house description and location of air inlets and extractor units.

2.3 Approach

The operating characteristics of the AERECO Humidity-Controlled Ventilation System was monitored using the micro-computer based data acquisition system with the appropriate instrumentation which permitted continuous automatic recording of all relevant parameters. Reliable and previously successfully used monitoring equipment (Sciemetric) and the computer software (PILOT ver 2.11 by Howell-Mayhew) had been used for continuous monitoring. A detailed monitoring protocol and procedure was developed to meet various objectives of this project.

Table 3: Summary of Houses and Ventilation Systems

	Morewood House (House A)	Carleton Place House (House B)
1. House Description	Split entrance raised bungalow Floor area - 109.7 m^2 Volume - 460.2 m^3 Electric baseboard heaters	Bungalow Floor area - 101.8 m^2 Volume - 414.9 m^3 Electric baseboard heaters
2. Location of Air Inlets	Living room (1) Master bedroom (1) Other bedroom (2) Basements (2)	Living room (1) Master bedroom (1) Other bedroom (2) Spare room (Basement) (1) Family room (Basement) (1)
3. Location of Extractor Units	Kitchen (1) Bathroom (1) Laundry area (1)	Kitchen (1) Bathroom (1) Laundry (1) Workshop (1)
4. Airtightness @ 50 Pa (Inlets at maximum position)	3.18 air change rate per hour	3.03 air change rate per hour

Appendix B provides the description of monitoring procedure. The monitoring system provided the collection of time-referenced data on the house and ventilation system performance. Monitored data was saved at fifteen minute intervals. The monitoring equipment and procedure was identical in both houses. The following data were recorded by data logging equipment:

1. **Relative Humidity (%):** The relative humidity was monitored at various points to establish whether the air-inlets and extractor units are responding to humidity variations as intended. The continuous monitoring of relative humidity provides information on the relationship between periods of house occupancy, effects of changes in human occupancy and changes in humidity (absolute and relative) on

time-referenced data (lead or lag timing). The humidity sensors were located in the following locations:

- outdoor
- living room: near the air-inlet (House B only) and in the centre of a room - maximum, minimum and average during 15 min time-interval
- master bedroom: in the room - maximum, minimum and average during 15 min time-interval
- exhaust duct connected to extractor fan unit

2. Vent Position (%): Air-inlet position were recorded to determine the air flow. The response of air-inlets to ventilation requirement is related to vent position. Vent position data can be used with the relative humidity to establish relationship between occupancy and the air inlet response. The time-referenced changes in the vent position also helps in identifying the operation of air inlets (appropriate, sluggish, slow, fast, or stuck). The vent positions were recorded in the following location:

   - living room: maximum, minimum and average position every 15 min interval.
   - master bedroom: maximum, minimum and average position every 15 min interval.

3. Temperatures (deg C): The temperature measurements were gathered in the following locations:

   - outdoor
   - living room: near the air-inlet (House B only) and away from inlet in opposite corner
   - master bedroom
   - exhaust duct connected to extractor fan unit
   - basement: - laundry room and workshop (House B)
     - centre of basement (House A)

4. CO_2 (ppm): The CO_2 is commonly used as an indicator of air quality. ASHRAE Ventilation Standard 62-1989 recommends a long-term exposure of CO_2 limited to 1000 ppm based on comfort and odour control. In Canada, the Health and Welfare Guidelines suggests a long-term exposure limit of 3500 ppm based on health considerations only. CO_2 in a house is primarily people generated and, hence, a good indicator of changes in the occupancy. In this project, the CO_2 data is used to establish relation between occupancy, relative humidity and air-inlet positions. The CO_2 sensors were positioned in the following locations:

   - outdoor
   - living room
   - living room air inlet in House B
   - master bedroom
   - exhaust duct connected to main extractor fan unit

5. **Wind speed (m/s):** The wind speed was measured to observe the influence of wind on the demand-controlled ventilation system. The wind speed sensor was located high above the roof.

6. **Power Consumption (W and kWh):** Electricity is the main fuel used in these houses. Energy and power monitoring data provides the energy consumption profile of these houses.

7. **Pressure (Pa):** The pressure difference across air-inlets or building envelope drives the air flow. The indoor-outdoor pressure difference across building envelope assists in determining air infiltration. The pressure difference across air-inlet and across extractor fan unit can be utilized in establishing the air flows through each equipment. The measurements can be also used to check the extractor fan flow measurements. The following pressure differentials are measured:

   - indoor-outdoor pressure differential
   - across the living room air-inlet
   - across the master bedroom air-inlet
   - across the extractor fan unit

8. **Air Flow (L/s):** Air flow rate is measured in the extractor units ducts from the kitchen, bathroom and basement. Summation of these flows is the total air exhaust from the house.

2.4 Instrumentation and Set-up

The AERECO ventilation systems and monitoring equipment were installed over a period of several weeks. The installation of the AERECO system comprises of the following components:

- 4 EMH Ventilators (air inlets) on the Main Floor
- 2 EMH Ventilators in the Basement
- 1 BNG 104 Air Extractor in the Bathroom
- 1 BNG 105 Air Extractor in the Kitchen
- 1 BNG 104 Air Extractor in the Basement laundry area
- 1 BNG 104 Air Extractor in the Basement work room area (House B only)
- 1 VPH 080 Central Exhaust Fan in the attic ducted to each air extractor

The AERECO equipment can operate on two different humidity settings. Initially all air extractors and air inlets on the main floor have been set on the low humidity setting while the air inlets in the basement were set to the high humidity setting. The scheme was chosen to give ventilation priority to the main living areas.

The ventilation system was installed in House A (Morewood) by Francis Fuels with supervision from Scanada. Air extractors were placed in the kitchen, bathroom and in the basement near the laundry area. Four air inlets were installed on the main floor: one in each of three bedrooms, and one in living room. Two additional air inlets were placed in the basement.

The ventilation system in House B (Carleton Place) was installed by Bell Air Conditioning with assistance from CAN-AERECO and Scanada. Air extractors were placed in the kitchen and bathroom on the main floor, and in the basement in the laundry room and in the workshop. Four air inlets were installed on the main floor: one in each of the three bedrooms, and one in the living room. Two additional air inlets were placed in the basement: one in the family room, the other in a spare unfinished room.

The computer data acquisition system and monitoring system was installed by Sciemetric Instruments with assistance and supervision from Scanada. Installation of the monitoring system was performed simultaneously with the installation of the AERECO ventilation system. The following is a list of components and a summary of the sensor deployment in both houses:

- IBM-PC compatible micro-computer, with dual floppy disk drives, monitor, modem, and Sciemetric Model 802 Interface card.
- phone line for remote communication
- MIRROR remote communication software package
- Sciemetric Model 161 Electronic Measurement System and 12 VDC power supply.
- PILOT ver 2.11 data collection and processing computer program
- Hammond box c/w 24 VDC power supply, Sciemetric RB01 relay card, and a 12 position Scanivalve with 3 fluid wafers.
- Nova Carbon Dioxide Analyzer, Model 300D
- Four (4) Sciemetric Model 107 RH Sensors (5 in House B)
- ECT Model LPTB-03-C Pressure Transducers
- Four Current Transformers
- Four Sciemetric RMS cards (one Model 108 & three Model 110)
- 500 feet of Beldon Cable, #8641
- 500 feet of Type T thermocouple wire
- 750 feet of poly-tube
- Three (3) ECT Flow Measuring Stations (5" round); Two ECT (5") in House B
- One (1) ECT Flow Measuring Station (6" round) - House B only
- Two (2) Hall Effect Transducers
- Three cup wind anemometer and mast

SENSOR DEPLOYMENT

Outdoors:	Temperature, RH, CO_2, wind speed
In Duct Before Fan:	Temperature, RH, CO_2, and delta P_{atm}
Master Bedroom:	Temperature, RH, CO_2, air inlet damper position, and delta P across air inlet
Living Room:	Temperature, RH, CO_2, air inlet damper position, delta P across air inlet (RH and Temperature at the air inlet - House B only)
Air extractors:	The flow rate through each of the air extractors. (Total basement flow only for House B.)
Main Electric Panel:	Total electric consumption and heating consumption in living room

The monitoring sensors were chosen with a view to analyze the following:

- Exhaust performance of each individual exhauster
- Total exhaust performance of the system as a whole (out-flow)
- Air inlet performance (in-flows)
- Effect of wind pressure on the operation of the ventilators and exhausters, and on CO_2 and RH levels
- Electricity consumption and demand
- Local energy needs of one heavily monitored room (the living room)

Monitoring was performed on a continuous basis by the computer equipment. Spot readings were taken using manual methods at several occasions during field trips to supplement and check the data acquisition system. These spot readings served two purposes:

1) analyzed data not directly being monitored by the computer equipment, and
2) verified the data acquisition equipment whether performing its job properly and collecting data accurately.

Appendix B includes a detailed installation, commissioning and calibration report of the monitoring of these two houses.

2.5 Monitoring Program

The monitoring of AERECO ventilation system was divided into following tasks:

1. **Commissioned AERECO Ventilation System and monitoring equipment:**

   AERECO Ventilation System was commissioned and monitoring was initiated after thoroughly verifying its operation. Home owners were thoroughly familiarized with the ventilation equipment, monitoring equipment, and its operation. Different modes of operation of ventilation system were demonstrated to home owners. Project team also explained House B home owners about the limitations involved in the use of wood stove with AERECO ventilation system. The home owners were requested to keep a brief record of operation of ventilation equipment, any abnormal operation and their comments on comfort aspects. The project team made several phone contacts with home owners to keep track of operation of the ventilation system.

2. **Monitored and tested continuous operation of AERECO system:**

   Ventilation system operating parameters were collected using the computerized data logging equipment. The data was collected at every 15 min interval and saved on diskette. Every week data

was transferred via modem to Scanada for performance analysis. Forty five elements were measured at an every 15 min interval - recording 4,320 points every day.

Field visits were performed at regular intervals to inspect the AERECO ventilation system, and to observe general conditions such as condensation on windows. During these visits, temperature, relative humidity, wind speed and CO_2 readings were taken with hand-held instruments. These readings were compared with data logging sensors. Every month the radon levels were measured, and formaldehyde concentrations were measured on 3 occasions.

3. **Analyzed the performance of AERECO ventilation components:**

   At regular intervals, the monitored data was analyzed to determine the performance of AERECO ventilation components. These results are presented in the following Sections.

2.6 General Observations

The Carleton Place house is occupied by two adults and two children. During week days, whole family arises between 6:00 AM and 7:00 AM. On most week days, everybody leaves home before 08:15 AM. The family returns home between 03:00 PM and 05:00 PM. They generally go to bed between 09:00 PM and 11:00 PM. There is a wood stove in the basement of this house. Monitoring results showed that the wood stove was used during Christmas time, in the month of January and February for a total period of 3 to 6 days. The house owner was cautioned with regards to the use of a wood stove, as it was found during the site visit that the wood stove was back drafting in the house.

The Morewood house is occupied by two adults and one baby. During week days, the whole family arises between 6:30 AM and 7:30 AM. On most week days, everybody leaves home before 08:30 AM. The family returns home between 03:00 PM and 05:00 PM. They generally go to bed between 09:00 PM and 11:00 PM.

3. RESULTS AND PERFORMANCE ANALYSIS

The Carleton Place house was monitored for the period from December 8, 1989 to April 13, 1990. The Morewood house was monitored from December 19, 1989 to April 5, 1990. Monitored data was examined and "typical" snapshots of three to four days were selected to determine the performance of the AERECO ventilation components and system as a whole. These snapshots were selected with a main objective of obtaining greater insight into the operation of the AERECO system under different conditions. These snapshots were for the period when the monitoring system was recording most variables without any problems. The following operating conditions were used in evaluating the AERECO system:

- periods of normal house occupancy and non-occupancy;
- the outdoor temperature: below -10 C, between 0 and -10 C, between 0 C and 10 C; and
- surge loads such as when several people enter (or leave) a room at the same time.

The performance analysis assists in determining the various product/system characteristics and the operating performance, such as:

- sensitivity to changes in relative humidity levels in outdoor and indoor air;
- influence on indoor air quality with the continuous monitoring of CO_2, and frequent sampling of radon and formaldehyde levels;
- reaction time to respond to changes in humidity;
- response time and catch up time for "surge" loads, such as when several people enter a room at the same time;
- influence of wind conditions and outdoor relative humidity on the operation of inlet units;
- performance of inlet units during periods of extreme cold (i.e., stiffness of operation, slow to respond, freeze up..); and
- evaluate apparent influence of the location of the inlet on the comfort levels in the room.

This section presents the performance results of both houses. The monitored results were adjusted with the appropriate correction factors to meet calibration needs where necessary.

3.1 Relative Humidity and Air Inlet Response

Humidity controlled air inlets rely on humidity as being the controlling variable determining the necessary ventilation rate. One of the objective of this project is to verify whether the use of humidity level is an adequate parameter in setting the ventilation rate. Analysis of air inlet response to relative humidity was performed for two scenarios using several snapshots: (i) during the normal occupancy periods, and (ii) surge loads.

3.1.1 Response of Air Inlets and Relative Humidity During Normal Occupancy

Air inlets in the Carleton Place house were set at (●) position (low altitude) to respond to changes in RH from 40% to 70% while the air inlets in Morewood were set at (+) position (high altitude) to respond to changes in RH from 25% to 60%.

Figures 1, 3, 7, 9, 17, 19, 21 show the variations in relative humidity (RH). With a variation in human activity, in most cases, the RH changes by 5 to 10%. As shown in Figure 1, the RH of the master bedroom in the Carleton Place house, increased from 36 to 42% during the period of activity from 06:00 to 07:00 hrs. Such a change in RH appeared to trigger the opening of air inlet from 37% to 45%. During this period, the fresh air flow through the air inlet changed from 3.4 L/s to 4.1 L/s.[1]

The average RH in the Morewood house was varying from 10% to 35% in most snapshots. This house was "dry" during the monitoring period which was also verified with hand-held measurements during site visits. Hence, any change in occupancy reflected relatively greater change in indoor RH. For example, as shown in Figure 27 the relative humidity in the living room increased from 18% to 28% with the increase in occupancy within a period of one hour. The air inlet position changed from 47% to 70% during this period. The estimated air flow through the air inlet varied from 3.7 L/s to 5.1 L/s during this period.

The air inlets were found to respond to changes in RH, since the air inlet position varied with changes in RH in the room. However, the estimation of air flow to the room through the air inlet showed insignificant changes in the air flow. The change in air flow varied from 0.5 L/s to at the most 2.0 L/s. Such a small change in the air flow is arguably insufficient in meeting the ventilation requirement as specified by CSA F326.

It was also observed that during the normal occupancy, air inlets responded sluggishly to small changes in RH. In most cases, the air inlets responded to changes in relative humidity within 15 to 30 min time interval. When there were sudden changes in occupancy, as shown in Figure 17, the increase in relative humidity is almost instant and the air inlet responded to such surge loads within the 15 min time interval. It should be noted that in many cases, the change in indoor RH is not as significant as the change in the opening of the air inlet.

The response of relative humidity to occupancy in the living room and master bedroom in the Carleton Place house is shown in Figure 36 and 17. As shown in these figures, there were large changes in CO_2 with occupancy. The changes in relative humidity were small and ranged from 3 to 10%. Similar trends were observed in various snapshots. It is also observed that the relative humidity levels do not appear to track the levels of human activity in any significant way.

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[1] Calculated using the measured values of inlet opening and ΔP across the air inlet. CSA Standard F326 recommends a ventilation rate of 10 L/s in bedrooms during occupied periods.

The effect of incoming fresh air on the RH sensing element of an air inlet was monitored by providing RH and temperature sensors near the air inlet. In both houses, the relative humidity and temperature readings were taken near the air inlet and in the centre of a living room. These are shown in Figure 3, 4, 9, 10, 21, and 27. The measurements show that during cold days the RH near the vent was significantly higher than at the centre of the room. The temperature near the vent was about 2 degree lower than at the centre of the room. The air inlet seems to respond to changes in RH near the vent rather than at the centre of a room.

3.1.2 Response of Air Inlets and Relative Humidity During Surge Loads

Several snapshots were observed to see the effect of "surge" loads on AERECO system and how it responds. The ventilation system showed quick response to changes when several people enter the room at the same time; however, it was sluggish to respond to changes when several people leave the room at the same time.

Figure 17 and 18 shows a typical snapshot when the family returned from a weekend trip. The house was unoccupied from Friday morning to Sunday afternoon. During this unoccupied period, the air inlets in living room and master bedroom were in the minimum opening position. The RH levels in all rooms remained constant. The CO_2 levels were constant almost at the outdoor level. When the family returned on Sunday at around 16:00 hrs, the ventilation system responded almost instantly. The air inlet in the living room started responding with the increase in the RH almost hand in hand. Within the first 30 min, the living room air inlet opened from 5% to 25% with a change in RH from 36% to 40% (estimated air flow rate of 1.4 L/s to 4.7 L/s). Within a period of one hour, the air inlet in the master bedroom responded to the change in RH from 26% to 35% and the air inlet opened from 30% to 40% with an estimated air flow changed from 3.9 L/s to 5.4 L/s. The AERECO ventilation system seems to respond quickly to these sudden increase in the occupancy. However, the room air inlet does not show very significant increase in the actual air flow. The surge load in most cases increased the air flow from 0.8 to 3.5 L/s which may not be sufficient enough to meet the ventilation requirement (as specified by CSA F326).

When the family leaves the home together, the ventilation system takes more than an hour to respond to the changes. The changes in room RH occurs slowly. The air inlets reacted slowly to changes in such sudden "unloading" of occupancy. However, the room CO_2 readings indicate sharp changes. The "surge" loads also showed that the CO_2 levels vary almost *instantly* to changes in occupancy. The CO_2 ascertains as a "reliable" occupancy indicator.

3.2 Carbon Dioxide and Air Inlet Response

The carbon dioxide (CO_2) is commonly used as an indicator of air quality in buildings. CO_2 levels were continuously monitored in the following locations: outdoor, living room, master bedroom and exhaust duct connected to main extractor fan unit.

The time-referenced snapshots of CO_2 are shown in Fig 2, 5, 6, 8, 11, 12, 18, 20, 28, 31, 32, 36, and 37. Unlike relative humidity (RH), CO_2 levels do appear to track the levels of human activity very well. Rise in CO_2 consistently occurs at the times of maximum activity. During unoccupied periods, the CO_2 level decays, as indoor air is exhausted from house by the extractor unit.

A typical snapshot is shown in Figure 2. The CO_2 level in master bedroom peaks at 1250 ppm and remains above 1000 ppm from 0:00 hrs to 06:00 hrs. During unoccupied periods from 06:30 to 20:00 hrs, the CO_2 level remains well below 1000 ppm in the master bedroom. In the living room, the CO_2 level remains in the range of 500 to 700 ppm during unoccupied hours and peaks at 1200 ppm with full occupancy during evening hours for a period of one hour and then decays. This trend was observed in both houses on most working days.

The reason for higher CO_2 levels for a period of four to seven hours in the master bedrooms during night hours may be attributed to the closing of the bedroom doors in both houses. In both houses, the master bedroom door undercut is less than 25 mm. The bedroom floor is carpeted. The closing of bedroom door thus reduces the exhaust air flow to a minimum. The increase in the CO_2 level in the living room is due to presence of the whole family in the living room. The CO_2 levels remain below 1000 ppm in the living room in most situations and this may be due to the unobstructed path for exhaust air flows.

It was also observed that at peak times, CO_2 levels in both houses exceed 1000 ppm. These higher CO_2 levels do indicate a lack of fresh air supply to the house. This peak CO_2 level does not indicate a severe air quality problem and does not exceed Health and Welfare Canada's guidelines for indoor air. However, CO_2 levels are relatively high in comparison to houses with the heat recovery ventilation (HRV) systems.

It was noticed that, in most cases, the peak levels of CO_2 above 1000 ppm remains for a period of three to seven hours and then the levels decay. These peak levels are not in equilibrium (or constant) for a long time. Hence the average CO_2 levels for these two houses, as indicated by the extractor flow CO_2 measurements, will be varying from 500 to 800 ppm and the effect of long term exposure to home owners may be based on these CO_2 levels.

The comparison of CO_2 and RH trends (Figure 36 and 37) shows that variations in RH are more smaller than changes in CO_2. The CO_2 tends to indicate *instantaneous* changes in the occupancy while the RH lags about 15 to 30 minutes behind changes in occupancy.

As shown in Figure 5, 6, 11, 12, 31, 32, the time-referenced comparison of CO_2 and air inlet response does not track well. During normal occupancy, the air inlet response to human activity is weaker in most cases. However, one or two hour averaged variations in CO_2 and air inlet response can be compared relatively well in either increasing or decreasing trends. This observation raises a question regarding whether the AERECO air supply inlets are effective in demand-controlled situations where the supply of fresh air is supposed to be provided on a room by room basis when necessary.

3.3 Other Air Quality and Performance Indicators

3.3.1 Sampling of Formaldehyde Levels

The formaldehyde sampling was taken three times in Carleton Place and twice in Morewood. (The mid-winter formaldehyde dosimeters from Morewood house were sent uncapped by the homeowner.) Table 4 shows the measurements of formaldehyde samples taken from the living room and master bedroom of these houses. For the December reading in Carleton Place, the master bedroom sample was substituted for a basement sample. This was done because the home owner installed wood stove just before Christmas and the family was spending more time in the basement during the month of December. Based on the low readings obtained in the basement, the master bedroom was tested for other sampling periods. The formaldehyde levels in the Carleton Place house varied from 0.029 ppm to 0.070 ppm. In the Morewood house, the formaldehyde levels were varying from 0.037 to 0.048 ppm. The Health and Welfare Canada recommends 0.1 ppm as a maximum acceptable limit for residential occupancy.

3.3.2 Sampling of Radon Levels

Table 5 shows the measurements of radon samples taken from both houses. The radon levels in the Morewood house were below 2.3 pCi/L. In the Carleton Place house the radon levels varied from 2.6 to 3.9 pCi/L in the living area and 2 to 12.2 pCi/L in the basement. Radon levels in the Morewood house are below the stringent American guidelines, while in the Carleton Place house, the radon levels are below the Canadian guidelines. Radon levels do not pose any health risks in both houses.

As the formaldehyde and radon samples were not taken prior to the installation of the AERECO ventilation system, it is difficult to assess the impact of demand-controlled ventilation on these air pollutants.

Table 4: Sampling of Formaldehyde

	December	February	March
Carleton Place House			
Living Room	0.070	0.050	0.040
Basement	0.029		
Master Bedroom		0.049	0.043
Morewood House			
Living Room	0.042		0.048
Master Bedroom	0.037		0.039

Table 5: Sampling of Radon

Morewood House

Test Date	Location In Basement	Radon Reading (pCi/L)	(mWL)	Test Method
Dec 18/90	At sump	1.35	6.76	Thompson Neilsen
Feb 05/90	At sump	2.31	11.56	Pilon

Carleton Place House

Test Date	Location In Basement	Radon Reading (pCi/L)	(mWL)	Test Method
Dec 08/90	At sump	2.00	10.00	Thompson Neilsen
Dec 13/90	At sump	2.64	13.20	Thompson Neilsen
Feb 01/90	At sump	2.99	14.95	Pilon
Mar 05/90	At sump	12.20	61.00	Pilon
	Family room	7.72	38.60	Pilon
Apr 02/90	At sump	3.86	19.29	Pilon
	Family room	2.60	12.99	Pilon

Note: Maximum acceptable limit in Canada 20 pCi/L or 100 mWL.
Maximum acceptable limit in the USA 4 pCi/L or 20 mWL.

All of the test results above were below the maximum acceptable Canadian levels but the readings of March 5 were both above the American level and the April 2 reading at the sump was just about at the 4 pCi/L, US-EPA level.

3.3.3 Condensation on Windows

The measurement of room air relative humidity does not necessarily represent the overall moisture content in the house. The surface condensation on walls or windows is a good indicator of moisture problems in the house. Moisture dispersion depends on the availability of sufficient and properly distributed ventilation in a house. In most houses the condensation on windows is a good indicator of moisture problems. Condensation on windows can result from poor quality of windows (product and installation), air leakage, thermal bridging, poor air and heat movement, and of course the high moisture levels in a house.

During the installation of the AERECO system, the project team found condensation on windows in the

living room and kitchen in both houses. After commissioning of the AERECO ventilation system, no condensation was observed on these windows in both houses. The air extractor units maintained continuous out flow of moist indoor air.

The AERECO system was shut off from Dec 9 to Dec 13 by the Carleton Place homeowner. A site visit by the project team on Dec 13 revealed condensation on the living room, kitchen and bedroom windows. The AERECO system was made operational during this visit. During a site visit on Dec 21, the AERECO system was satisfactorily working and no signs of condensation was seen on windows. The continuous air exhaust through extractor units was assisting in maintaining the lower relative humidity. AERECO system was found to be working satisfactorily in maintaining the lower moisture levels in these houses.

3.4 Performance Analysis

The effectiveness of AERECO ventilation system was examined by performing the following analyses:

- comparing the unintentional house leakage area and the intentional leakage area provided by air inlets;
- the balancing of air in-flow from air inlets and house leakage, and the exhaust air from extractor units; and
- impact on monthly energy consumption when compared with conventional ventilation system.

3.4.1 Comparison of Intentional and Unintentional Leakage Area

House A and B were first tested for airtightness and were sealed to obtained the air change rate lower than 3 air changes per hour (ac/h) at 50 Pa before installation of AERECO system. Comparison of airtightness results shows that these houses are relatively tighter than most new detached houses in Canada [Hamlin et. al. 1990]. The average air change rate (@ 50 Pa) of new detached housing stock is 3.4. Before analyzing the monitored data, it is important to examine the importance of the unintended air leakage area (ELA) and the intended air supply area provided by the air inlets.

In both houses, a ratio of intentional opening area (IOA of air inlets) to the total house leakage area (ELA) varies approximately from a minimum of 12% (all air inlets minimum position) to a maximum of 27% (all air inlets fully opened). This suggests that a significant amount of ventilation air is entering the house through non-intentional openings. The IOA/ELA ratio can be increased by further air-sealing the building envelope and/or increasing the number of air inlets. However, one should weigh the implications of increasing the IOA/ELA ratio in terms of overall house performance.

The airtightening of the house will have an effect on the indoor/outdoor pressure balance. The further airtightening will have certain implications: it will result in higher house depressurization which might increase the radon levels and might result in back-drafting of naturally aspirated combustion appliances. The stack and wind effects would also increase fluctuations in ΔP.

The increase in the number of air inlets would result in a reduction in house indoor/outdoor pressure balance. The reduction in ΔP across the indoor and outdoor may result in less air flow through the air inlets and may have a negative impact on the fresh air distribution. The pressure reversal (indoor pressure higher than outdoor) may cause the indoor air to escape through the air inlets causing frost built up on inlets.

3.4.2 Air In-flow and Out-flow Balance

For the analysis purpose, the AERECO ventilation system is divided into two circuits: air in-flows through the air inlets and the house envelope leakage area; and air out flow (exhaust) through extractor units.

The air in-flow through air inlets can be determined using the measurements of ΔP across the air inlet and the vent position (opening area). It can be expressed as:

$$Q = S\,(\Delta P)^{1/2}/(3.6)$$

where, Q is the flow (L/s)
S is the vent opening area (cm^2)
ΔP is the difference of pressure across the air inlet (decapascal)
C is the flow coefficient (assumed 0.9)

The air leakage through the building envelope can be determined using the following correlation [ASHRAE 1989]:

$$Q = ELA\,(A\Delta T + Bv^2)^{1/2}$$

where, Q is the infiltration flow through the building envelope (L/s)
ELA is the equivalent leakage area (cm^2)
ΔT is the indoor/outdoor temperature difference (C)
v is the wind speed (m/s)
A is stack coefficient ($(L/s)^2(cm)^{-4}(C)^{-1}$)
B is wind coefficient ($(L/s)^2(cm)^{-4}(m/s)^{-2}$)

Table 6: Stack Coefficient, A

	House Height (stories)		
	One	Two	Three
Stack Coefficient (A)	0.000145	0.000290	0.000435

Table 7: Wind Coefficient, B

Shielding Class	House Height (stories)		
	One	Two	Three
1. No obstruction or local shielding	0.000319	0.000420	0.000494
2. Light local shielding; few obstructions, few trees or small shed	0.000246	0.000325	0.000382
3. Moderate local shielding; some obstructions within two house heights; solid fence; neighbouring house	0.000174	0.000231	0.000271
4. Heavy shielding; obstructions around perimeter; buildings or trees within 10 m; typical suburban shielding	0.000104	0.000137	0.000161
5. Very heavy shielding; typical downtown shielding	0.000032	0.000042	0.000059

The extractor flow was measured in three places: extractor from the kitchen, the bathroom and the basement. The in-flow and out-flow calculations were done for different situations using the instantaneous flow measurements. These calculations are presented in the following table.

1. **December 15, 1989 Time: 18:45:** The recorded measurements were:
   Outdoor temp was -18 C; wind speed was 0.3 m/s; outdoor RH was 12%; indoor temperature varied from 19.5 in the master bedroom to 21 C in the living room; the living room RH was 45% and the master bedroom RH was 33%; CO_2 level in the living room was 850 ppm and in the bedroom it was 730 ppm; living room vent was 38% open and master bedroom vent was 30% open. The total extractor out flow was 53.8 L/s. The indoor/outdoor ΔP was 3.5 Pa. It was also assumed that other air inlets were 30% open and the ΔP across these inlets was similar to that of the living room air inlet. With these assumptions, the following flows were determined using the above correlations:

The air infiltration flow due to envelope leakage:	39.0 L/s	(72.5%)
The air in-flow through all six air inlets:	14.8 L/s	(27.5%)
Total air in-flow:	53.8 L/s	

   The 53.8 L/s air flow for this house is equivalent to 0.46 air changes per hour.

2. **January 8, 1990 Time 06:30 am:** The recorded measurements were:
Outdoor temperature was -3 C; wind speed was 1 m/s; outdoor RH was 72%; indoor temperature was 19 C; the living room RH was 30% and master bedroom RH was 44%; CO_2 level in the master bedroom was 1,050 ppm while in the living room it was 750 ppm; the master bedroom vent was 70% open and the living room vent was 27% open. The total extractor out-flow was 41.7 L/s. It was also assumed that other air inlets were 30% open and the ΔP across these inlets was similar to that of living room air inlet. With these assumptions, the following flows were determined using the above correlations:

The air infiltration flow due to envelope leakage:	32.3 L/s	(77.5%)
The air in-flow through all six air inlets:	9.4 L/s	(22.5%)
Total air in-flow	41.7 L/s	

The 41.7 L/s air flow is equivalent to 0.36 air changes per hour.

Several other calculations were performed to observe the trends in the air in-flow through the air inlets and exhaust from extractor units. The following observations were made:

The air flow through the air inlets varied from a minimum of 12% during non occupancy periods to a maximum of 27% during full occupancy. The estimated total air flow through all air inlets varied from 6.5 L/s to 16 L/s. The air leakage through the house envelope remained as a predominant form of fresh air supply to the house. Hence, even with full opening of the air inlets (say 90 to 95%), the fresh air supply to the rooms would not substantially increase. The air inlets did not seem to have control over where the fresh air was supplied. The fresh air will most likely be supplied to the basement where the majority of the leaks occur.

The continuous air exhaust was maintained by the air extractors. The flow measurement results showed that these units were working according to their settings and on an average provide 47 L/s of exhaust in both houses. Figure 23 and 24 shows the measured flows of extractor units in Carleton Place house. The total extractor flow was varying from 18 L/s during unoccupied periods to 65 L/s during peak kitchen activities. These extractors were constantly exhausting air from the house and kept the house depressurized from 3 to 7 Pa or more.

3.5 Influence of Outdoor Conditions: Wind and Temperature

December 1989 was a record breaking cold month. The average ambient temperature remained below -15 C for most of the month of December. The AERECO system was commissioned in this time period.

It was observed that in some cases (twice in Carleton Place and once in Morewood) when the outdoor temperature was below -15 C and with the prevailing wind conditions, the air inlets were stuck in one position. Data analysis for those periods showed the following:

In Morewood, the house indoor/outdoor pressure balance was fluctuating and creating a positive pressure across the living room air inlet which resulted in "exhausting" moisture-laden indoor air through air inlets. The outdoor temperature was varying from -15 to -21 C and the wind velocity during this period was varying from 3 to 4.4 m/s. The living room air inlet vent was positioned stuck at about 30% position for a period two days. After that, the air inlet vent position started to vary again (outdoor temperature was varying from -3 to -7 C). During this period, the air inlet in the master bedroom was working and showed no abnormalities. During the field visits, the air inlets were checked and no abnormalities were found.

From Dec 9 to 13, in Carleton Place house the extractor fan was shut off by the home owner in order to use the wood stove. The house indoor/outdoor pressure showed fluctuations creating positive pressure across the air inlet in the living room and master bedroom. During the field visit of Dec 13, ice flakes and icicles were present on the air inlet housing outside. However, no abnormalities were found near the air inlet vanes.

In the first week of January in the Carleton Place house, the monitored data showed that the air inlet in the living room was not changing position for a period of two days. The ΔP reversal is shown in Figure 25 and 26 - please note that the +ve ΔP when inside pressure is lower than outside. Other data showed that the extractor units were running properly and all other conditions were normal. It seemed that the high wind velocity (4 to 5 m/s) might have created local positive pressure across the air inlet and thereby allowing the "exhaust" of indoor air. Sudden temperature changes (from -15 C to -3 C) might have assisted in defrosting the air inlet. The living room air inlet was found to work properly thereafter.

3.6 Occupant Response

The comments expressed from the two homeowners were very different. The owner of House A had very few complaints and had quite a hands off approach to the entire project. On the other hand, the owner of House B was very involved and concerned about many aspects of performance and effects on his energy consumption etc.

Morewood House (House A)

The occupants of this house were very satisfied with the performance of the AERECO ventilation system. No complaints were expressed except when asked during one of the site visits. Cold drafts were felt occasionally in the living room at night when the winds were from the direction of the air inlet. Besides that the homeowner never had any problems with condensation or any uncomfortable drafts in the bedrooms.

Carleton Place House (House B)

General complaints of the house being too cold were expressed by this home owner throughout the month of December. At the beginning of the month of December there was no source of heat in the basement except the wood stove. Electric baseboard heaters were installed in the basement to ensure that the wood

stove would not be used and the monitoring could proceed. Most of the complaints from the homeowner were during this period when he was using the wood stove and the AERECO ventilation system was not working as intended. Complaints of air inlets frosting up and cold drafts from the air inlets were mostly during this initial period when the home owner was fighting the system rather than understanding the principle and allowing the system to do its work as intended.

From January on, there were no complaints about the system operation except for a concern that the air exhausters were never fully closed. The home owner was worried that there was too much air being exhausted from the house since these air exhausters never closed and this would affect his energy bills. The homeowner was quite happy with the indoor air quality and even commented that they had had less respiratory problems than before this winter.

The Carleton Place homeowner was also concerned about the AERECO system being not designed to work with wood stoves. He had expressed views that, like his family, many Canadian families would like to use wood stoves without affecting the performance of ventilation system while maintaining indoor air quality.

4. DISCUSSION

The field monitoring program was designed to evaluate the applicability of AERECO ventilation system in the harsh Canadian climate. The continuous monitoring of ventilation system provided better insight into the operation of AERECO system under different weather conditions. This section presents the discussion on monitored results.

4.1 Relative Humidity and Air Inlet Response

The field monitoring was designed with an intent of gauging how well the ventilation system and house respond to increases and decreases in indoor humidity.

Normal Occupancy: With variation in human activity, in most cases, the RH changes by 1 to 10%. The AERECO ventilation system is a humidity-controlled system and in its current configuration the air inlets do not show *instant* response of air inlet to the changes in room humidity. When there is a small increase in RH (1 to 3%) due to normal human activity (CO_2 level rises more than 15%), the air inlet response times are slow and the resulting increases in ventilation rates are very slight. Air flow through the individual air inlet vary from 0.8 L/s to a maximum of 1.7 L/s. The time-referenced data on RH and air inlet position did not necessarily followed each other, for example, a slight increase in RH might have been followed by the closing of the air inlet rather than the opening. The relative humidity levels did not appear to track the levels of human activity in any significant way during normal occupancy.

Surge Loads: Several snapshots were observed to see the effect of "surge" loads on the AERECO system to evaluate its "quick" response. The ventilation system showed quick response to changes when several people entered the room at the same time; however, it was sluggish to respond to changes when several people left the room at the same time. The quick response of the air inlets opening when a sudden increase in the occupancy increased the air flow from 0.8 to 3.5 L/s in most cases. The CO_2 levels increased heavily during "surge" loads and remained high (in some cases more than 1000 ppm) for a period of more than 2 hours. This indicates that the air flow through the air inlets during sudden "loading" may not be sufficient to meet the ventilation requirements of occupants at that time.

Relative humidity is found to be a poor indicator of occupancy. Response times are slow and often there is no discernable change in RH despite major changes in occupancy and CO_2 concentrations. Relative humidity displays lag time with changes in occupancy mostly due to absorption and desorption characteristics of the house.

4.2 Carbon Dioxide and Air Inlet Response

Unlike relative humidity, CO_2 levels do appear to track the human presence and levels of activity very well during normal occupancy and for the "surge" loads. A rise in CO_2 consistently occurs at the times of maximum activity. During unoccupied periods, CO_2 levels decay, as indoor air is continuously exhausted from house by the extractor units. Presumably, CO_2 can be a good indicator of occupancy and indoor air quality with demand-controlled ventilation systems.

In the Carleton Place and Morewood houses, the CO_2 levels in the master bedrooms peaked at more than 1000 ppm and remained above this level for a period of three to seven hours during the night time. The CO_2

levels were also high (however lower than 1000 ppm) in the living room during normal occupancy mostly in the evenings or weekends. The reason for higher CO_2 levels in the bedroom may be attributed to the closing of the bedroom door in both houses. The bedroom door undercut was smaller than 25 mm in both houses. The closing of the bedroom door drastically reduced the exhaust air flow from that room.

The higher CO_2 levels indicate the lack of supply of fresh ventilation air to the house. It is probable, therefore, that the current air inlet system is not providing adequate fresh air flow to the house. However, the homeowners had no complaints of stale air or inadequate ventilation, and seemed pleased with the air quality and comfort of their homes. Although CO_2 is a good indicator of occupancy, the demand-controlled ventilation systems, like AERECO, would require a combination of CO_2, indoor relative humidity and minimum ventilation sensors to provide quality ventilation in Canadian houses.

4.3 Comparison of Indoor Carbon Dioxide and Relative Humidity

The comparison of CO_2 and RH trends shows that variations in RH are more stable and smaller than changes in CO_2. The CO_2 tends to indicate *instant* changes in the occupancy while the RH lags about 15 to 30 minutes behind changes in occupancy. The time-referenced comparison of CO_2 and air inlet response do not track each other well. However, one or two hour averaged variations in CO_2 and RH response can be compared well in either increasing or decreasing trends. This observation raises the question regarding whether the AERECO air supply inlets are effective in demand-controlled situations where the supply of fresh air is supposed to be provided on a room by room basis when necessary.

The comparison of CO_2 and air inlet response also showed that the air inlets do not necessarily track the presence of occupancy in the room. Hence the claim that these inlets respond to occupant ventilation requirements is difficult to ascertain in most snapshots (Figure 5, 6, 11, 12, 31, 32). The comparison of CO_2 and room relative humidity levels showed that the CO_2 is a more "reliable" indicator of presence of occupancy than the relative humidity.

4.4 Performance of AERECO Ventilation System

Both monitored houses are tighter than "typical" houses in Canadian housing stock [Hamlin 1990]. The airtightness test value of these houses were lower than 3 ach at 50 Pa. It is important to examine the importance of unintended air leakage area and the intended air supply area provided by the air inlets.

In both houses, an intentional opening area (IOA of air inlets) to the total house leakage area (ELA) ratio varied approximately from a minimum of 12% (all air inlets in minimum position) to a maximum of 35% (inlets in maximum position). This suggests that a significant amount of ventilation air is entering the house through non-intentional openings.

The in-flow and out-flow calculations showed the following results for both houses: The fresh air flow through air inlets varied from a minimum of 12% during non occupancy periods to a maximum of 27% of the total air in-flow during full occupancy. Estimated total air flow through all air inlets varied from 6.5 L/s to 16 L/s. The air leakage through the house envelope remained as a predominant means of supplying fresh air to the house. Therefore, even if all air inlets were fully opened (say 90 to 95%), it would not substantially increase the fresh air supply to the rooms. The air inlets do not seem to have control over where fresh air is supplied. The fresh air will most likely be supplied to the basement where the majority of the leaks occur.

In this regard, the air inlets are of questionable value except where the air leakage patterns are uneven and require additional leakage in a specific applications such as in a small isolated room.

The IOA/ELA ratio can be increased by increasing the number of air inlets or by further tightening the house envelope. With higher IOA/ELA ratio (say more than 50%), the air inlets will still not be in control of necessary air supply where it is needed. The increase in the number of air inlets might also increase the drafts due to cold air supply and affect comfort.

The performance analysis of exhaust system showed that the continuous air exhaust was maintained adequately by the air extractors. The flow measurement results showed that these units were working according to their settings and on an average provided 47 L/s of exhaust in both houses. These extractors were constantly exhausting air from the house and kept the house depressurized from 3 to 7 Pa.

The energy efficiency of the AERECO system is achieved by cutting back the fresh air provided to the house occupants (presumably, at times when it is not required). However, the results of air quality monitoring (CO_2) in both houses raise questions about the suitability of humidity control as an exclusive control for ventilation rates. A heat recovery ventilator (HRV) system operated at low speed would achieve similar energy efficiencies while providing occupants with two or three times as much fresh air when needed and better CO_2 control.

4.5 Suitability of AERECO system in Canadian Houses

There are several other aspects which should be examined to establish the suitability of AERECO ventilation system in Canadian housing. The following discussion explores these issues:

- Natural ventilation, infiltration and exfiltration is driven by pressure differences caused by wind, temperature differences between indoor and outdoor (stack effect), and the operation of appliances, such as combustion devices and ventilation systems. These combined infiltration / exfiltration driving forces determine the indoor/outdoor pressure differences at various locations across the building envelope. The point at which the interior and exterior pressures are equal is called the Neutral Pressure Level (NPL). Above this point, the interior pressure is greater than the exterior (pressurized); below this point, the greater exterior pressure causes airflow into the building (depressurized) during the heating season.

  In relatively tight one storey houses, with continuous air exhaust, the NPL remains near the ceiling and maintains the house under negative pressure most times. The local pressure difference at air inlets in most circumstances will allow air to flow into the house. The local wind effects may cause local pressurization momentarily as observed in this project, but these circumstances are relatively few.

  In one-and-half or 2 storey houses the NPL, in most cases, remains well below the 2nd storey ceiling - ASHRAE suggests about 0.7 to 0.85 the height of a two storey house during the heating season. In such houses, the wind and stack effects would have a greater influence on the pressure balance across the air inlets than in a one storey house. The air inlets located in the second storey would be prone to air flow reversals which would affect their performance severely. Frequent flow reversal across air inlets would cause condensation or icing on the inlet flaps due to the exfiltration of moisture laden indoor air. The currently available AERECO air inlet components are not designed to handle such

flow reversals. The AERECO ventilation system should be evaluated in such applications.

- Eastern Ontario's winter climate is dry relative to coastal climates but is far from being dry when compared to prairies. The outdoor RH varied from 12% to 35% during the months of December, January and February. The occupancy generated humidity levels are relatively more pronounced in such climates. The AERECO ventilation system showed a better response to changes in the relative humidity in both houses due to generally lower RH levels in the houses. However, it remains to be seen how the AERECO system would respond to the high humidity climates.

- It is also important to note that AERECO system is not compatible with the forced air heating system, because the proper operation of the system depends on the local differences of RH to direct the fresh make-up air into those room that are occupied. When used with hydronic, baseboard electric, or radiant heating, some fresh is introduced into individual rooms according to their level of occupancy.

- AERECO air inlets supply controlled amount of fresh air when the inside pressure is lower than the outside at the air inlet. During winter months, in most cases, house may remain depressurized due to combined effects of airtightness and wind and stack pressures, which may assist in maintaining the local ΔP across air inlet favourable to supply fresh air. However, during spring and fall months (mild climate), the wind and stack pressures may not be favourable in keeping the house depressurized. This may be further aggravated by window opening during mild periods which could result in short-circuiting of air inlets and, hence, poor air distribution. The AERECO ventilation system may not be able to provide sufficient ventilation during these mild months. These aspects should be considered in examining the application of AERECO system in Canadian houses.

4.6 General Observations

- The intent of this project was to monitor the performance of the AERECO ventilation system. The project team installed the ventilation system in two houses and observed the daily operation. The AERECO ventilation components appear to be well designed and manufactured. The air inlets are trouble free at most times. The extractor fans and sensing devices are sturdy and no abnormal problems were encountered during the monitoring. The extractor fans and ducting are not noisy. The ventilation system is found to be easy to install even in retrofit situation.

- The monitoring equipment has worked well and provided valuable information in studying the ventilation system.

- The "passive" air supply system provides some ventilation at all times no matter how much or how little air it moves in and out of the building. It has proven to be an effective moisture control ventilation system in these two new, relatively tight houses since no window condensation problems were experienced despite their moisture load (construction moisture, firewood stored in the basement in House B, all of the cooking moisture and bathroom moisture, laundry everyday in House B etc.). The hands off controls of the AERECO system is an advantage over other house ventilation systems which are controlled by a wall mounted humidistat. Often these systems do not operate because the occupants keep the humidistat setting too high in the winter or fail to adjust the humidity settings according to the outdoor temperatures. The AERECO system is controlling the moisture well and air inlets are providing some fresh air to the occupants although it may not be sufficient.

5. CONCLUSIONS

The following conclusions can be drawn from the monitoring of two houses:

- With variation in human activity, in most cases, the RH changes by 1 to 10% in these houses. The AERECO ventilation system is a humidity-controlled system and in its current configuration, the air inlets respond to large relative humidity increases almost immediately during "surge" loads. However, when there is a small increase in RH due to normal occupancy, despite the fact that large increase in the CO_2 level occurs, the air inlets response time is slow and the resulting increases in ventilation rates are very slight. The air flow through the individual air inlet varies from 0.8 L/s to a maximum of 3.5 L/s. The relative humidity levels do not appear to track the levels of human activity accurately. The ventilation system was sluggish to respond to ventilation requirements of normal occupancy due to low changes in room relative humidity associated with the occupant's activities.

  The ventilation system showed quick response (within 30 min) to changes when several people entered a room at the same time; however, it was sluggish to respond to changes (more than 2 hours) when several people left the room at the same time. The quick response of air inlets to sudden increase in the occupancy increased the air flow from 0.8 to 3.5 L/s (per air inlet) in most cases.

- The CO_2 levels do appear to track the human presence and levels of activity very well. A rise in CO_2 consistently occurs at the times of maximum activity. Presumably, CO_2 can be a good indicator of occupancy and indoor air quality in demand-controlled ventilation systems. With AERECO system there is a weak correlation between the occupancy (CO_2) and the response of the air inlets (vent position). Although CO_2 is a good indicator of occupancy, the demand-controlled ventilation systems, like AERECO, would require a combination of CO_2, indoor relative humidity and minimum ventilation sensors to provide quality ventilation in Canadian houses.

- In both houses, the CO_2 levels in the master bedroom peaked at more than 1000 ppm and remained above this level for a period of three to seven hours during the night. It is probable, therefore, that the current air inlet system is not providing adequate fresh air supply to the house. However, the homeowners had no complaints of stale air or inadequate ventilation, and seemed pleased with the air quality and comfort of their homes.

- The in-flow and out-flow calculations showed the following results for both houses: The fresh air flow through air inlets varied from a minimum of 12% during non occupancy periods to a maximum of 27% of the total air flow during full occupancy. The air leakage through the house envelope remained as a predominant form of fresh air supply to the house. In this regard, the air inlets are of questionable value except where the air leakage patterns are uneven and require additional leakage in a specific applications.

- The performance analysis of the exhaust system showed that continuous air exhaust was maintained adequately by air extractors. The flow measurement results showed that these units were working according to their settings and on an average provided 47 L/s of exhaust in both houses. The total extractor flow varied from 18 L/s during unoccupied periods to 65 L/s during peak activities.

- The energy efficiency of the AERECO system is achieved by cutting back the fresh air provided to house occupants, presumably, at times when it is not required by the house occupants. However, the results of air quality monitoring (CO_2) in both houses raised questions about the suitability of humidity control as an exclusive control for ventilation rates.

- The monitoring equipment has worked well and provided valuable information in studying the ventilation system.

- The AERECO ventilation components appear to be well designed and manufactured. The air inlets are trouble free most of the time. The extractor fans and sensing devices are sturdy and no abnormal problems were encountered during the monitoring.

RECOMMENDATIONS

The main objective of this project was to study the performance and effectiveness of AERECO humidity-controlled ventilation system. The ventilation system was thoroughly monitored in two houses during the winter months of December 1989 to April 1990. Based on monitoring results and performance analyses, the following recommendations would assist in improving the effectiveness and performance of the AERECO system. These recommendations should be thoroughly evaluated by the manufacturer before implementing the product and/or system improvements.

Air Inlets:

The performance of air inlets should be improved by providing an inexpensive one-way flap, which would avert the problems created by air flow reversals. This unidirectional control of air flow through air inlets should be further evaluated.

The air inlets appear to be useful in places where the building air leakage patterns due to envelope ELA are uneven and require additional leakage area to supply fresh air. However, this change of application would require evaluation of each air inlet installation on the basis of house envelope leakage distribution.

Extractor Units:

The extractor units are performing according to their specifications. The use of air extractor units in the kitchen, bathroom and in all living spaces, such as bedrooms, living rooms, would certainly improve the air movement in the house and also would ensure the proper removal of stale air. In this regard, each extractor unit can be adjusted to provide continuous air exhaust according to the CSA F326 Standard.

System:

The AERECO humidity-controlled ventilation system is configured to provide fresh air through its air inlets in the living spaces when required. The extractor units are located in the bathrooms and kitchen. Extractor units continuously exhaust stale air. This configuration is ideally suited for the house when it remains constantly depressurized, and has unrestricted indoor air movement. However, due to the wind and stack effects the house indoor/outdoor pressure balance fluctuates which may create flow reversals across the air inlets. The closing of room doors, particularly bedrooms, restricts the air movement severally. Such inlet flow reversals and restrictions in air movement deteriorate the ventilation system performance and effectiveness. These situations occur quite often in Canadian climates. The project team recommends that the configuration of AERECO system should be further evaluated on the basis of the following modification:

The air inlets should be only used in places where the building air leakage patterns due to envelope ELA are uneven and require additional leakage area to supply fresh air. The building envelope leakage area provides more than 70%, or more, of the fresh air requirements to the house in most cases. The envelope leakage distribution plays an important role in providing the fresh air to the house. In certain places in the house, the envelope leakage is higher than other rooms. Providing the air inlets in those "tight" places would provide the fresh air supply.

Provide air extractor units in bathrooms, kitchen, bedrooms, living rooms and other habitable spaces. The air extractor units in each room will maintain continuous air exhaust. Each extractor unit should be specified to meet the CSA F326 requirements depending on the type of habitable space.

The above configuration of air inlet and exhaust system would maintain the ninimum "point" ventilation at all times during non-occupancy periods and would also provide required ventilation in rooms when needed during occupancy. The continuous exhaust through closed rooms (bedrooms) would assist in proper air movement. The continuous exhaust through different points would also aid in keeping the local ΔP at the air inlets in required range almost all times.

These modifications should be further evaluated.

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6. Scanada Consultants Limited, *To Study and Monitor the Operating Characteristics and Performance of the AERECO Humidity-Controlled Ventilation System*, Phase I Report, Prepared for Energy, Mines and Resources Canada, Ottawa, Ontario, December 1989.

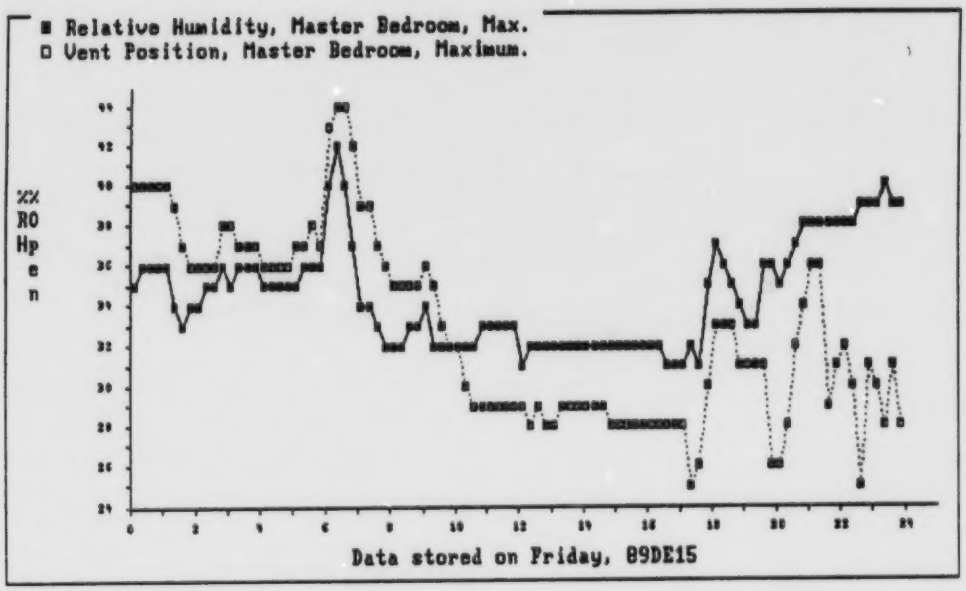


Figure 1: Relative humidity and air inlet response in Carleton Place house.

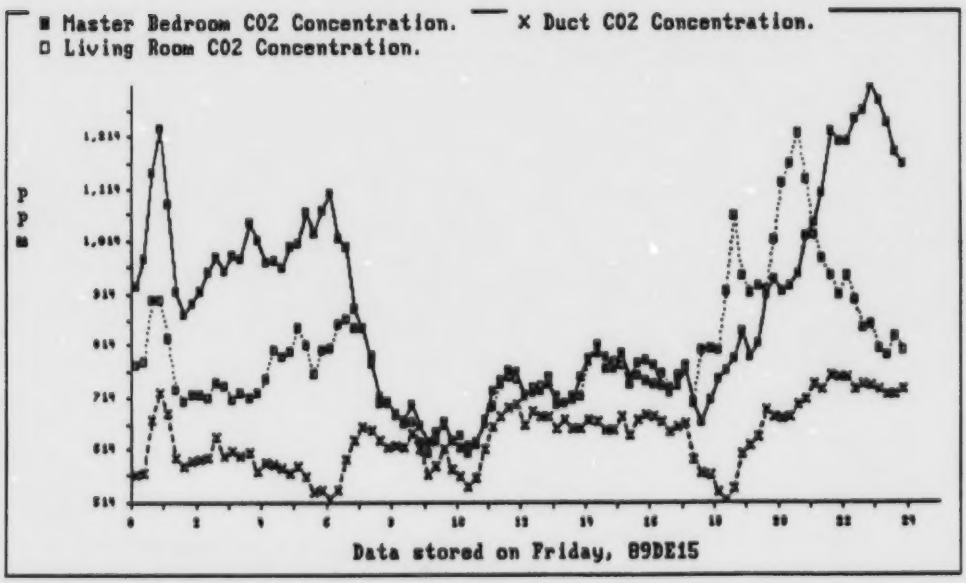


Figure 2: Variations in CO_2.

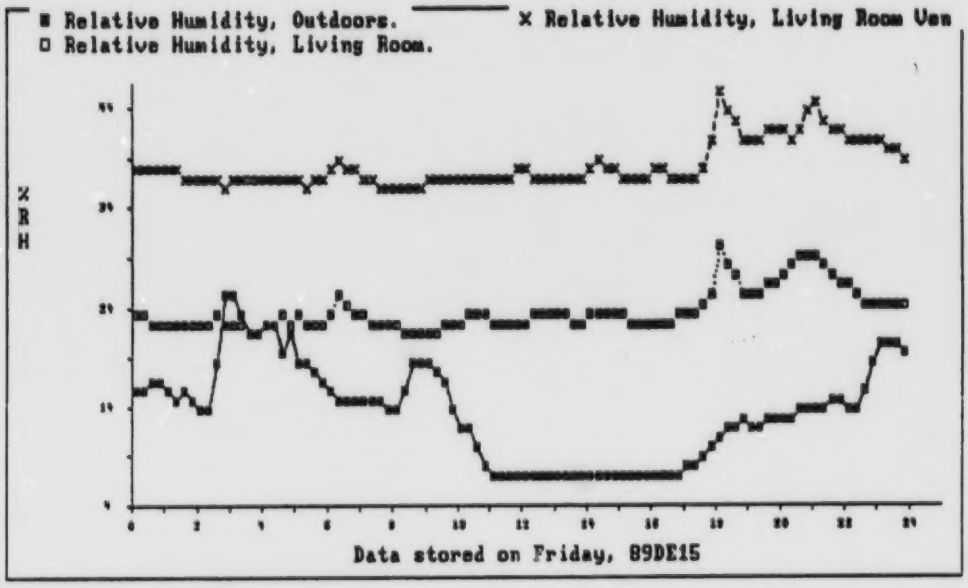


Figure 3: RH at vent and in the living room - outdoor temperature was -18 to -24 C

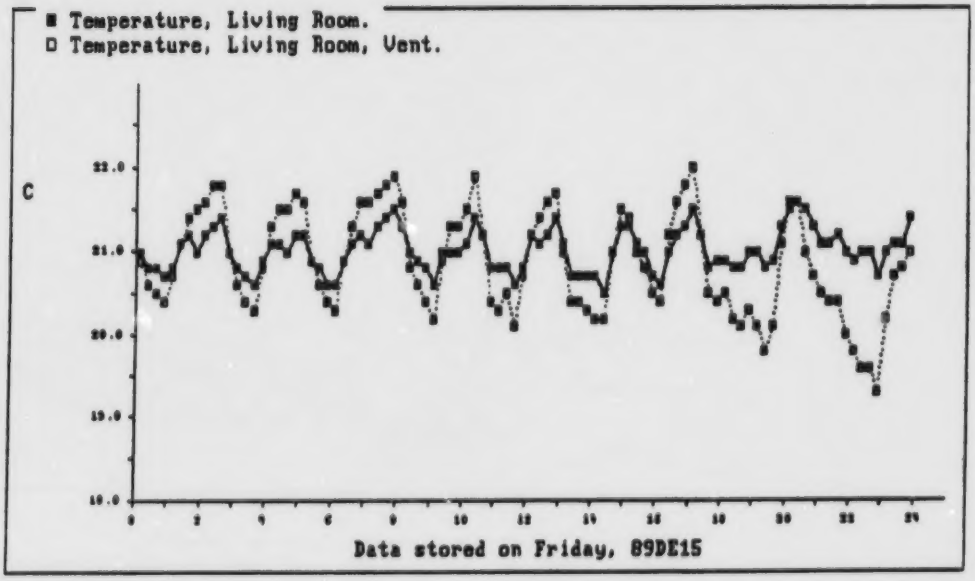
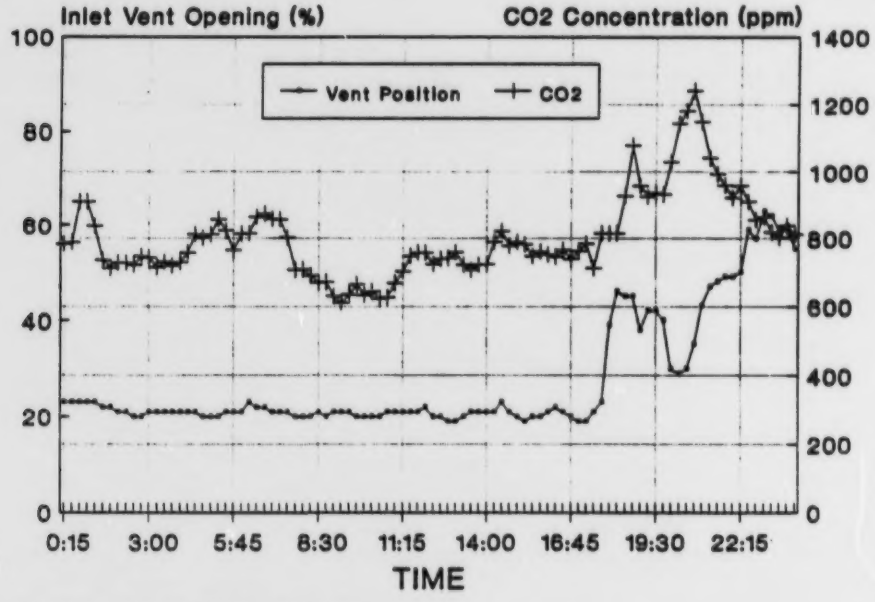
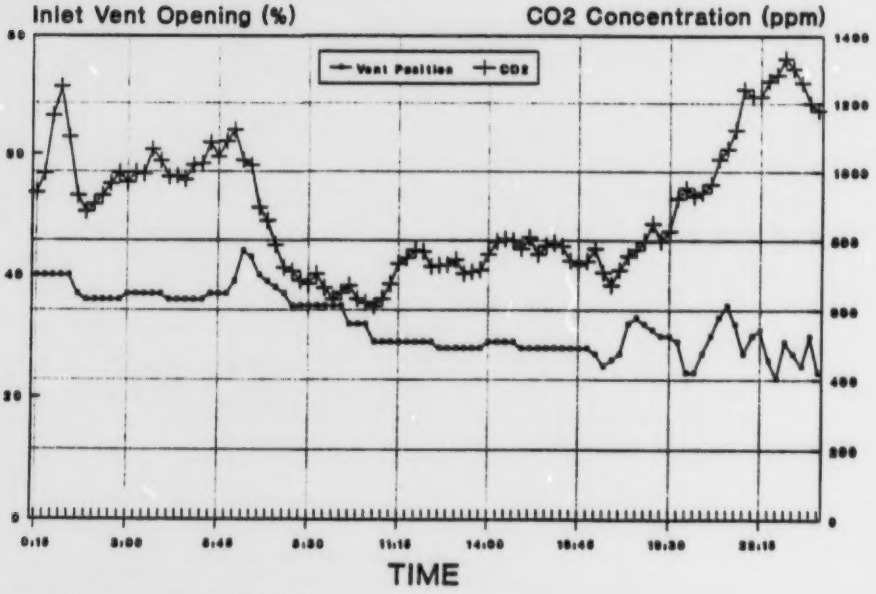


Figure 4: Temperature at vent and in the living room



Dec 15, 1989 - Living Room, Carleton

Figure 5: Response of air inlets to occupancy - living room



Dec 15, 1989 - Bed Room, Carleton

Figure 6: Response of air inlets to occupancy - master bed room

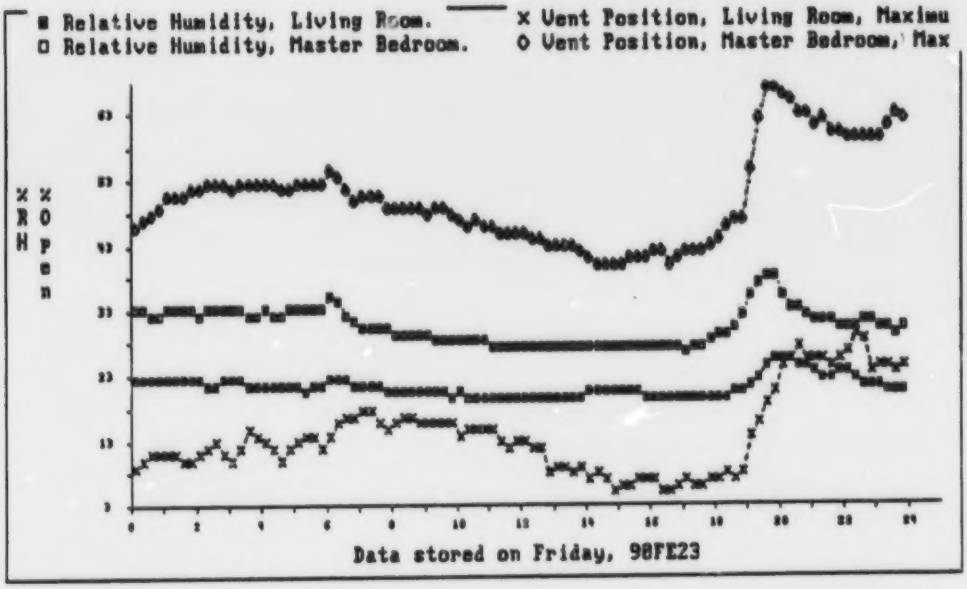

Relative Humidity, Living Room.
Relative Humidity, Master Bedroom.
Vent Position, Living Room, Maximu
Vent Position, Master Bedroom, Max
%RH %Open
Data stored on Friday, 98FE23

Figure 7: Relative humidity and air inlet response.

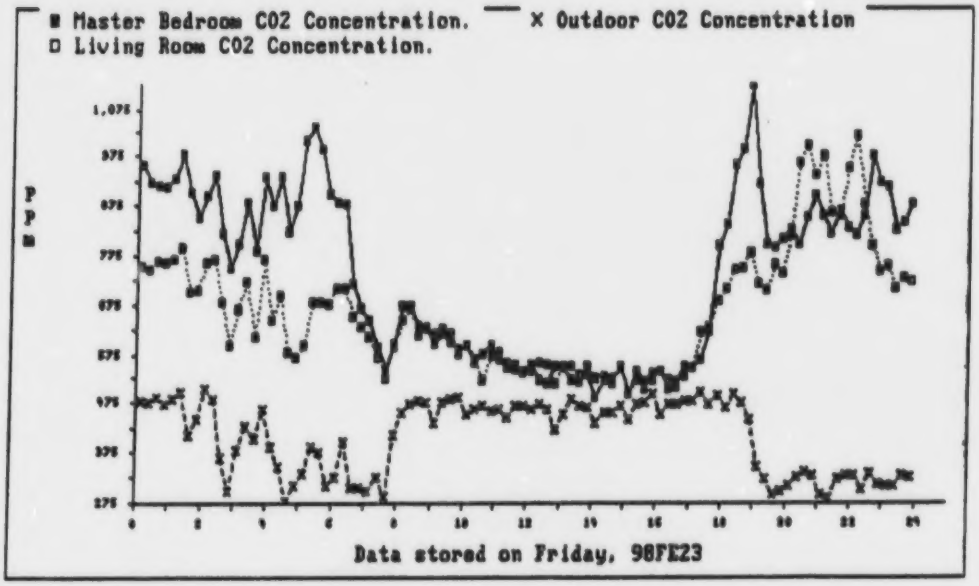


Figure 8: Variations in CO_2.

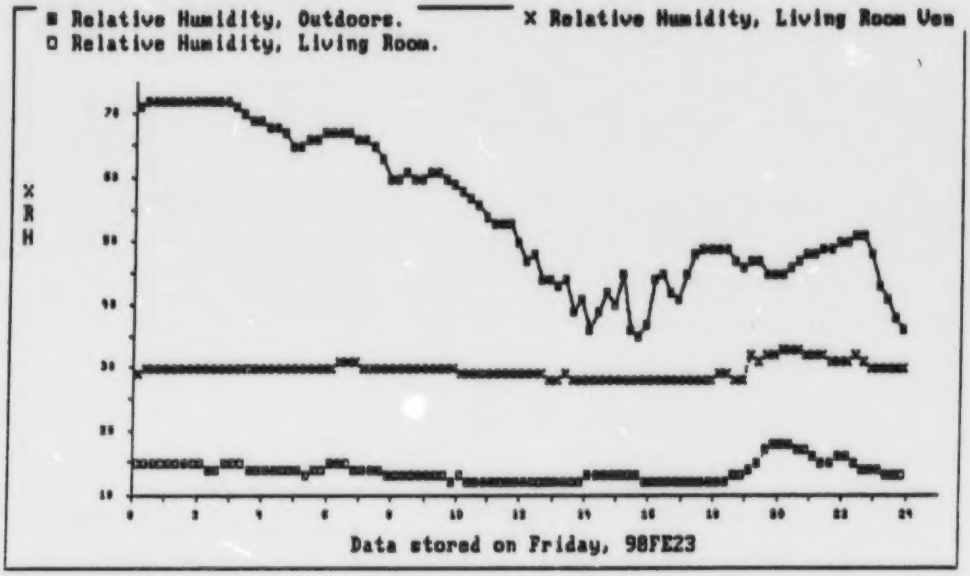


Figure 9: RH at vent and in the living room

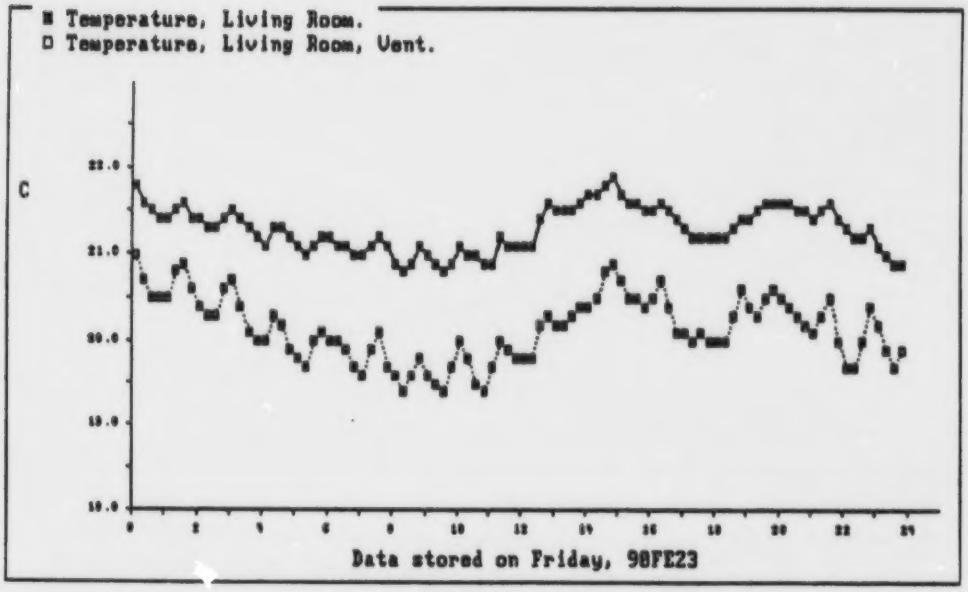
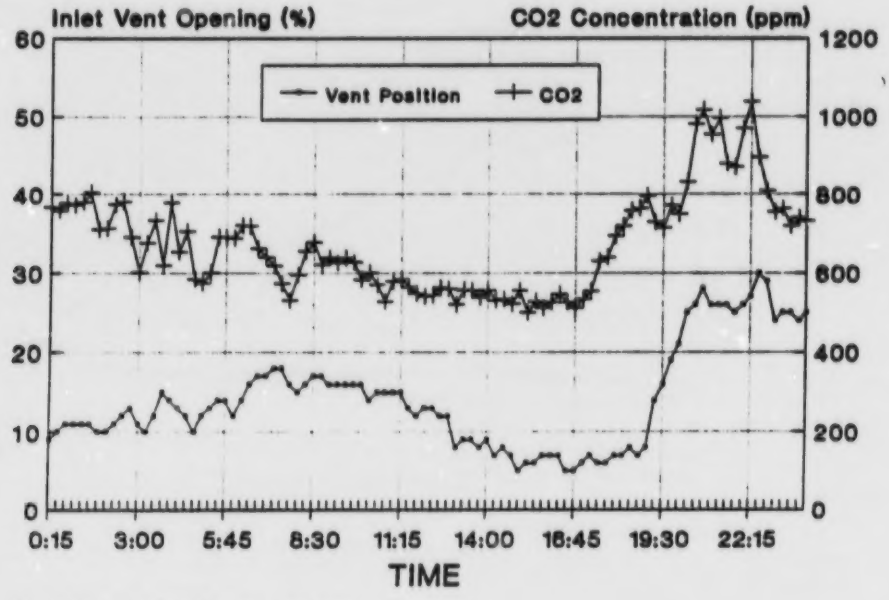
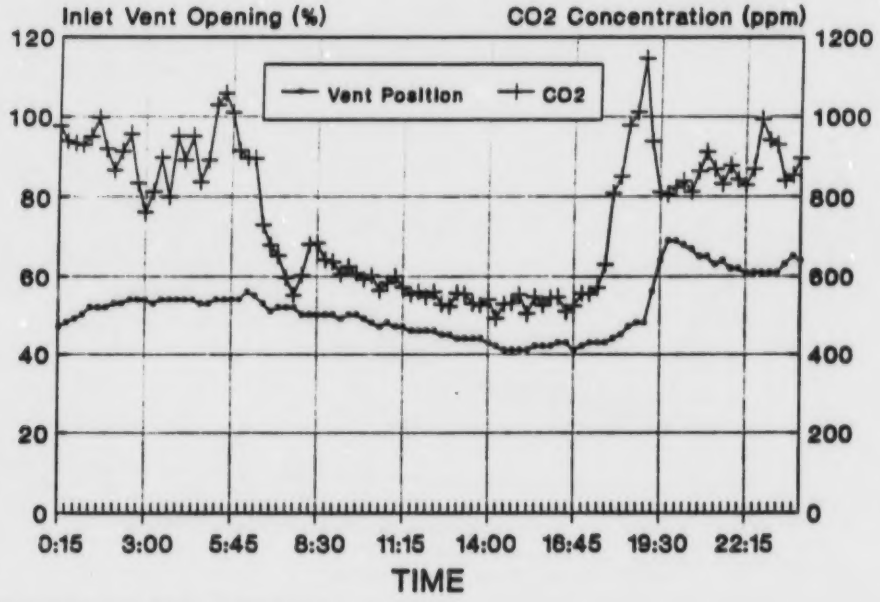


Figure 10: Temperature at vent and in the living room



Feb 23, 1990 - Living Room, Carleton

Figure 11: Response of air inlets to occupancy - living room



Feb 23, 1990 - Bed Room, Carleton

Figure 12: Response of air inlets to occupancy - master bed room

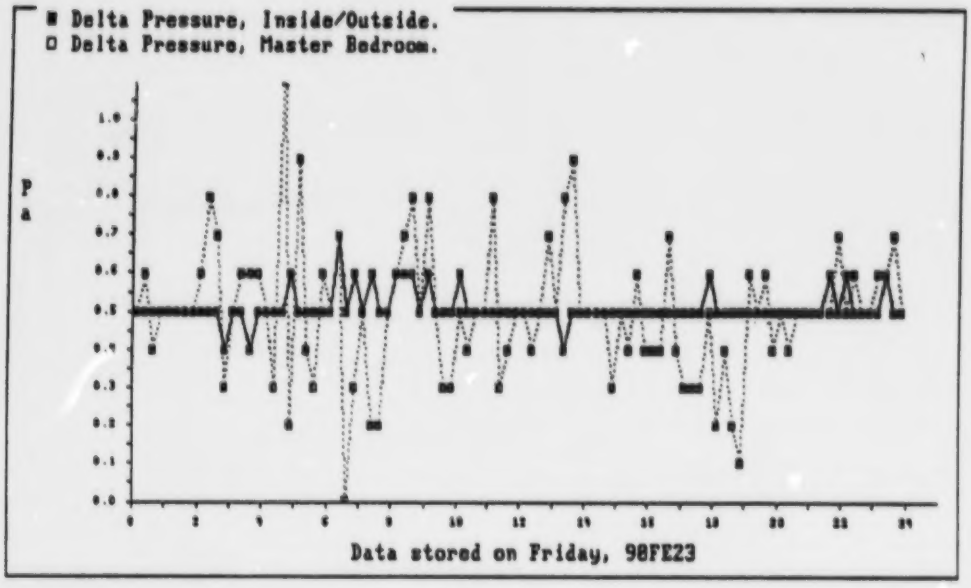


Figure 13: ΔP measurements (inside pressure lower than outside)

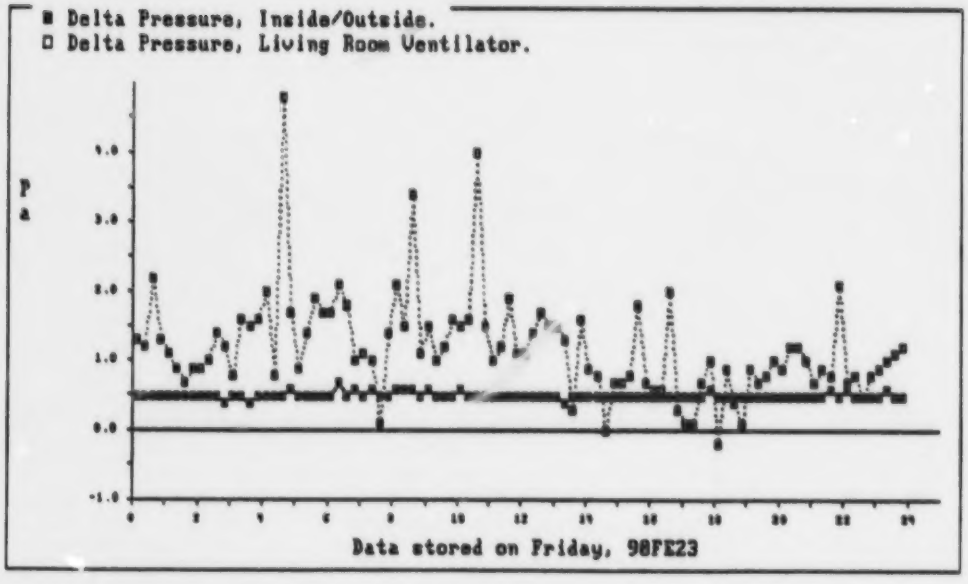


Figure 14: ΔP variation across living room ventilator (inside pressure lower than outside)

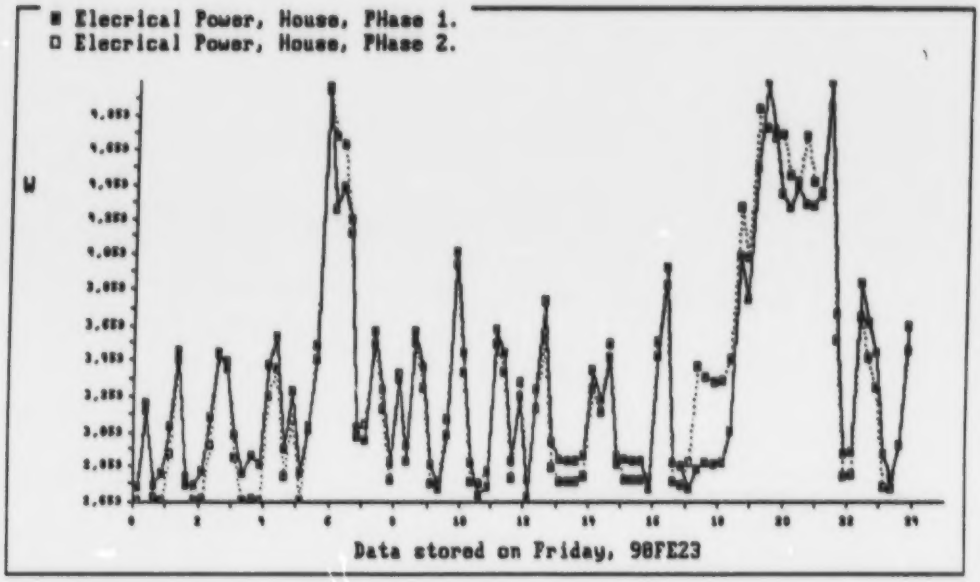


Figure 15: Power Consumption

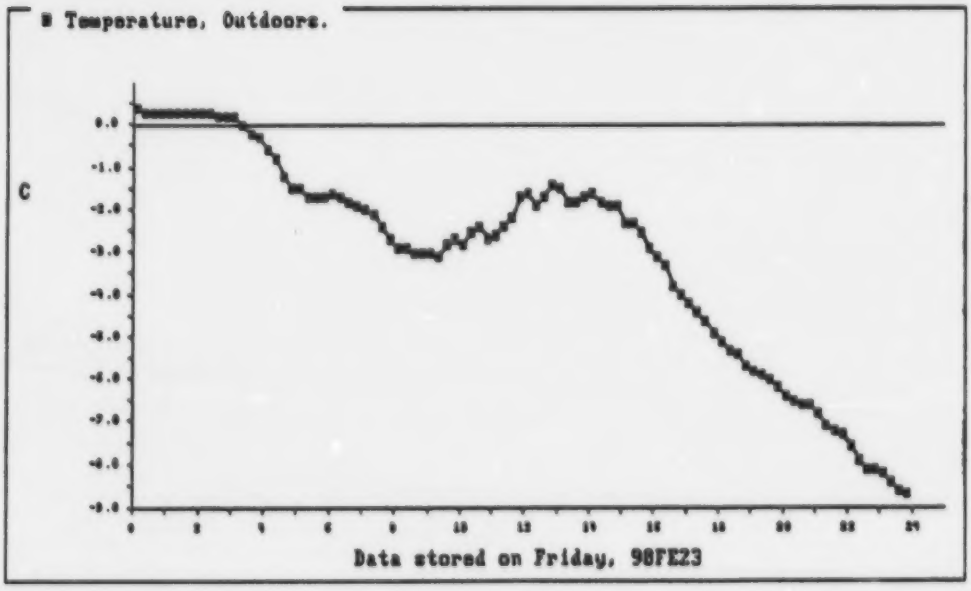


Figure 16: Outdoor temperature

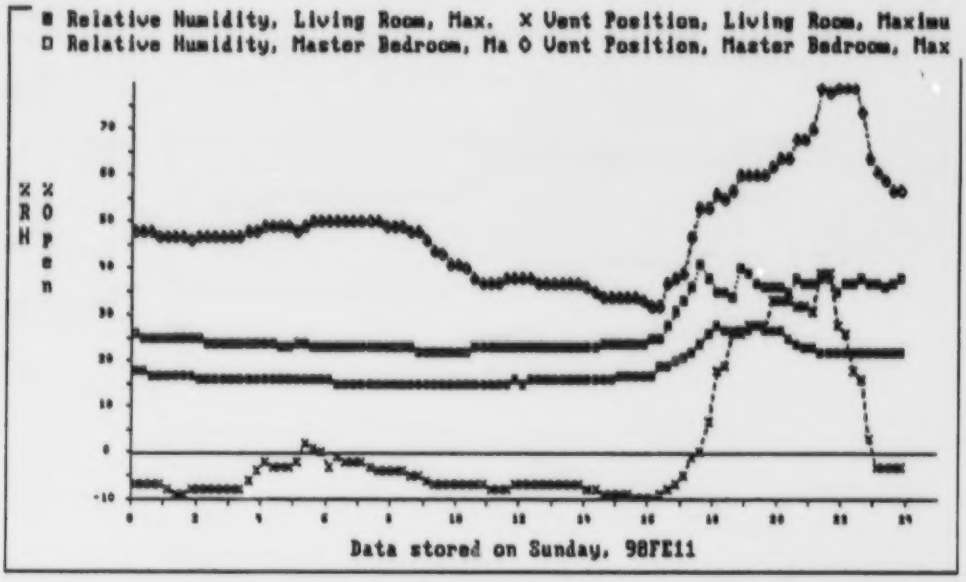


Figure 17: Effect of surge loads on RH and vent opening.

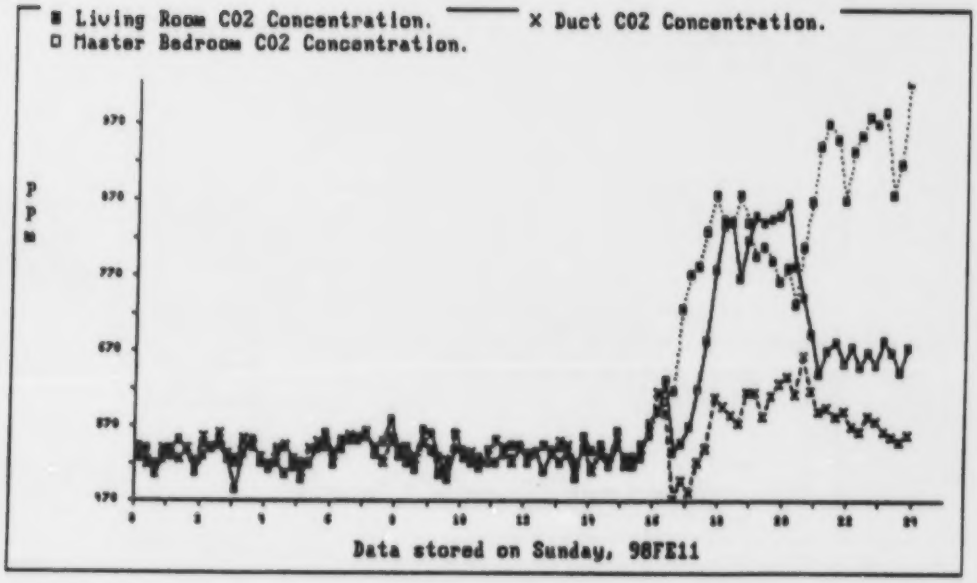


Figure 18: Effect of surge loads on CO_2.

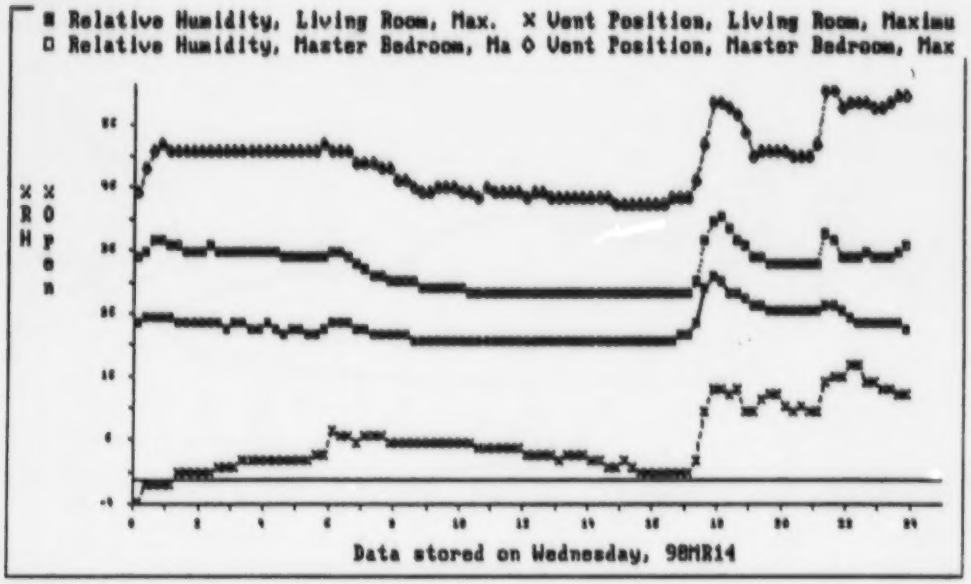


Figure 19: Snapshot of RH.

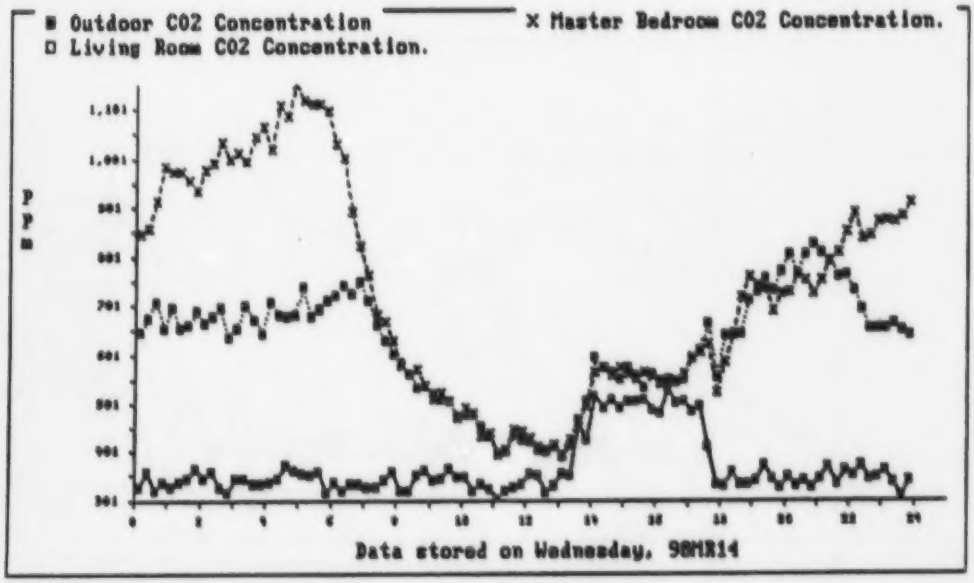


Figure 20: Snapshot of CO_2.

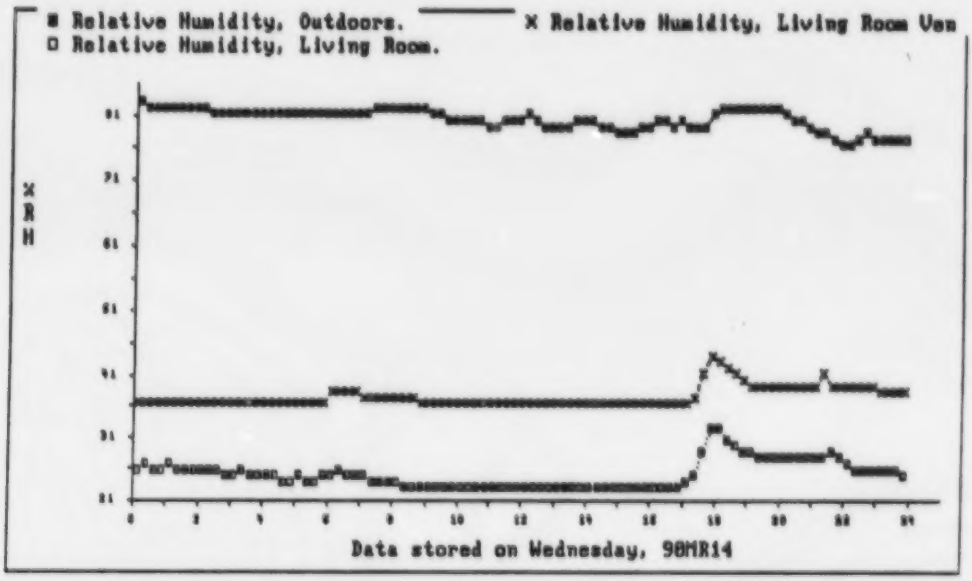


Figure 21: RH at vent and in the living room

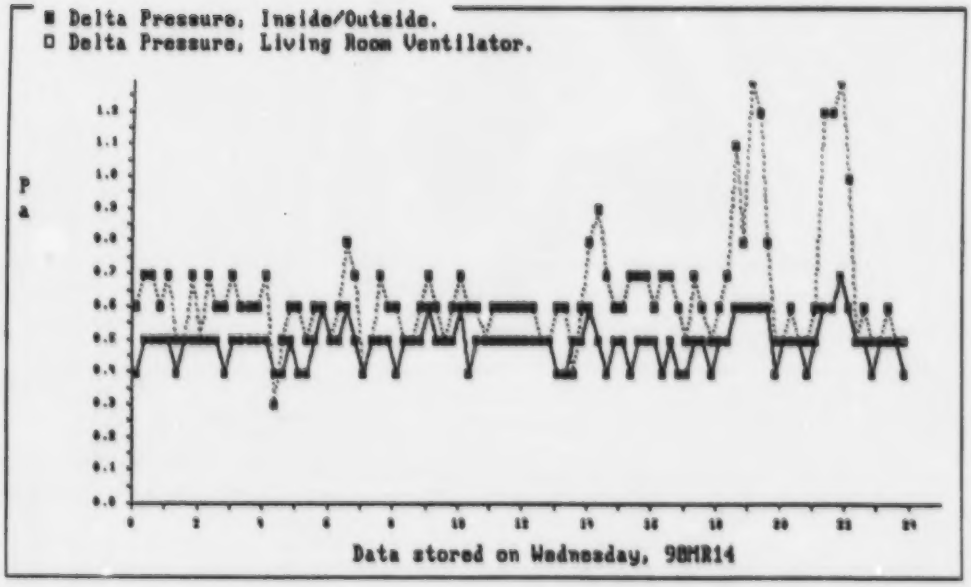


Figure 22: Pressure variations across living room air inlet

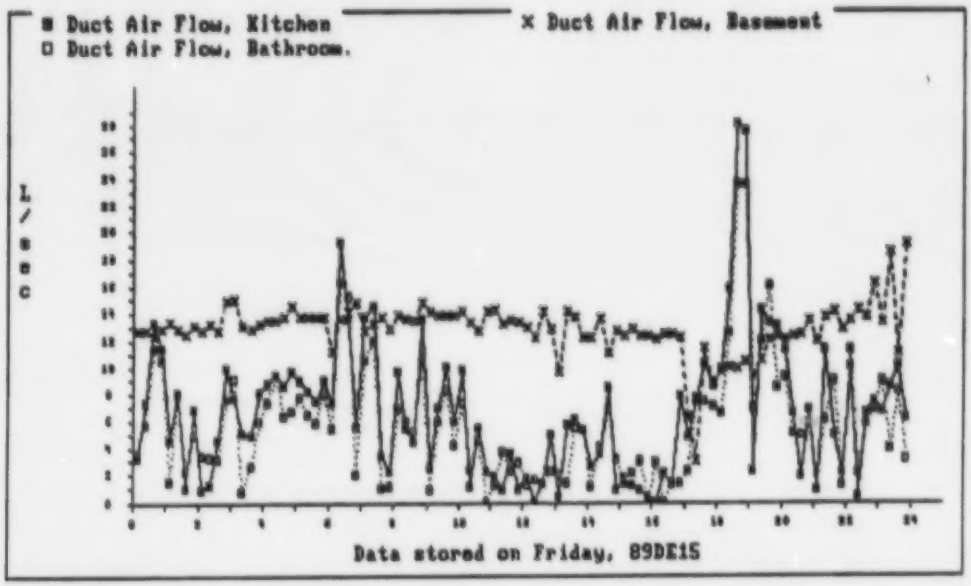


Figure 23: Extractor Flows

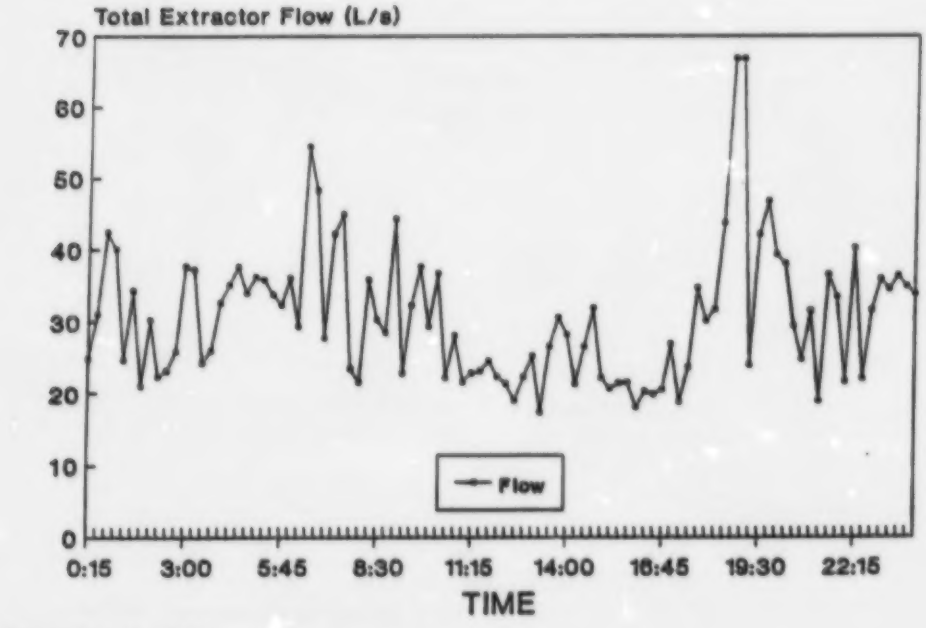


Figure 24: Total extractor air flow.

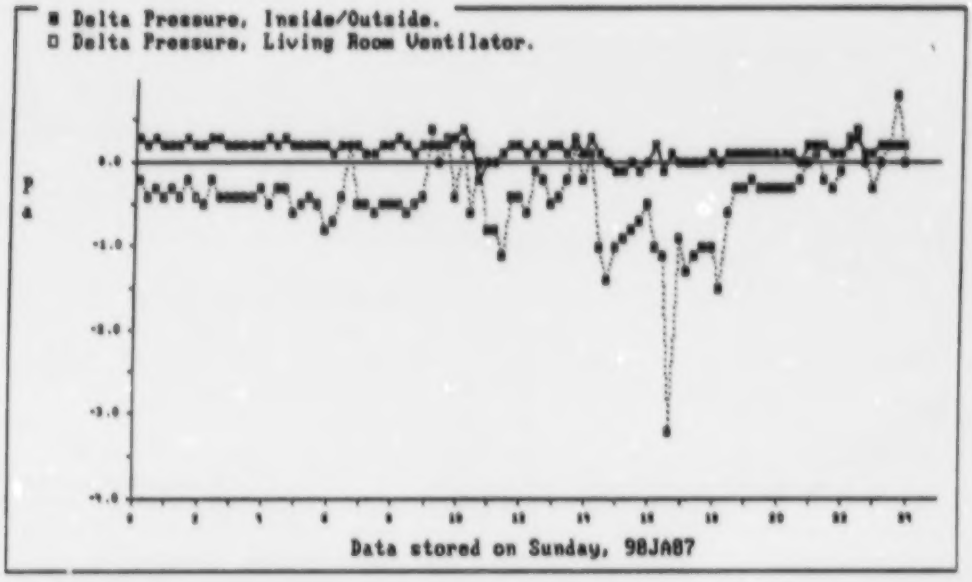


Figure 25: ΔP variations (+ve when inside pressure is lower than outside)

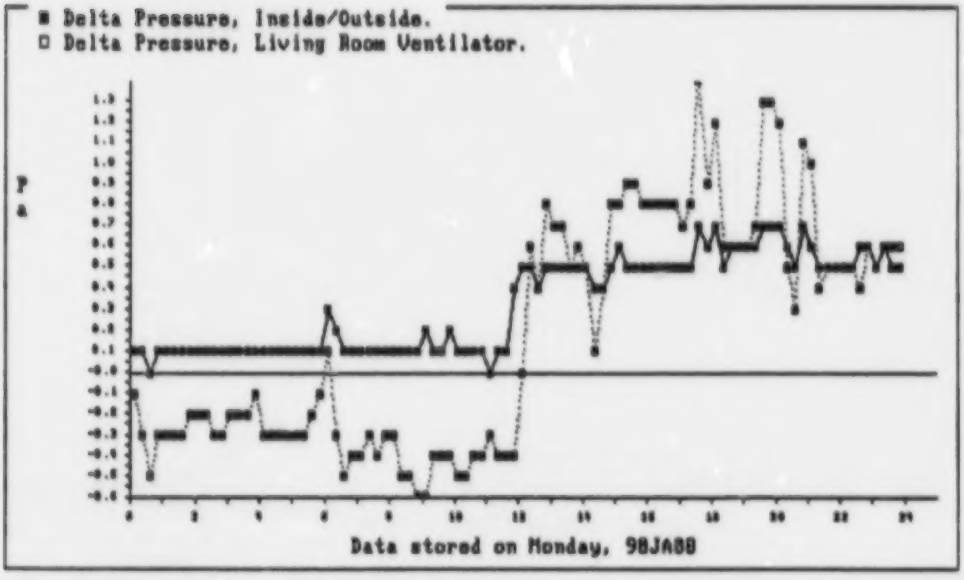


Figure 26: ΔP reversal (+ve when inside pressure is lower than outside)

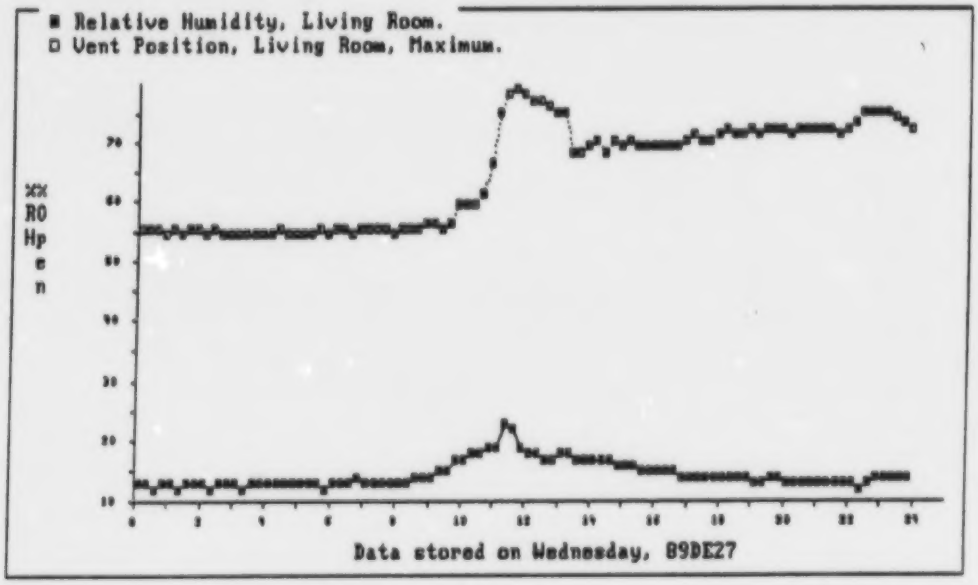


Figure 27: RH and vent position (Morewood)

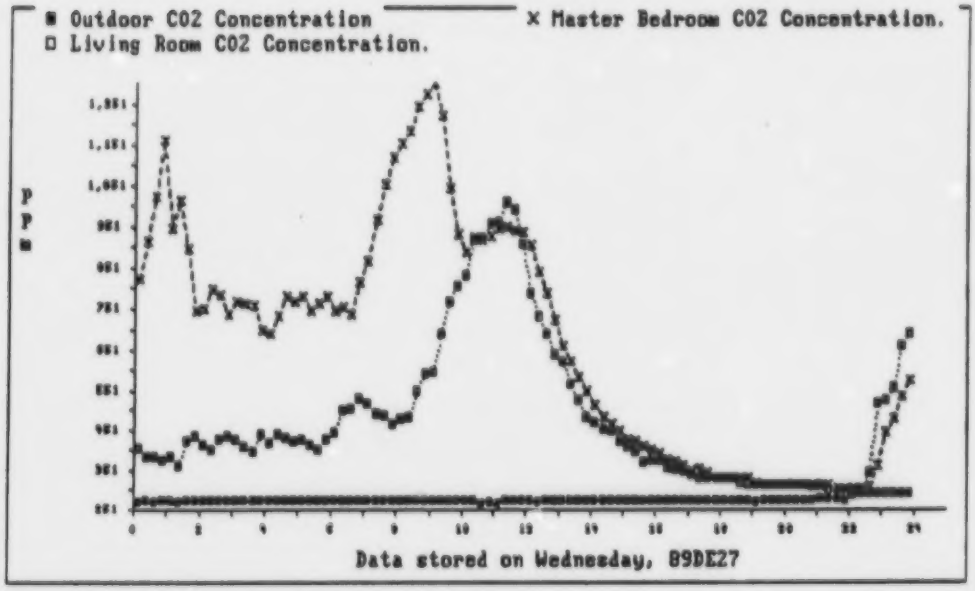


Figure 28: CO_2 variations (Morewood)

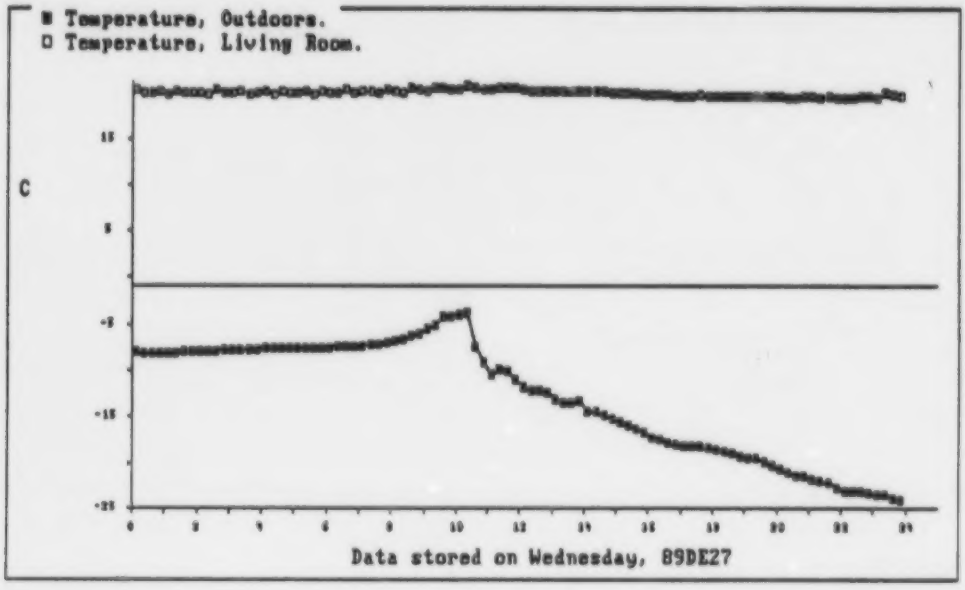


Figure 29: Temperatures (Morewood)

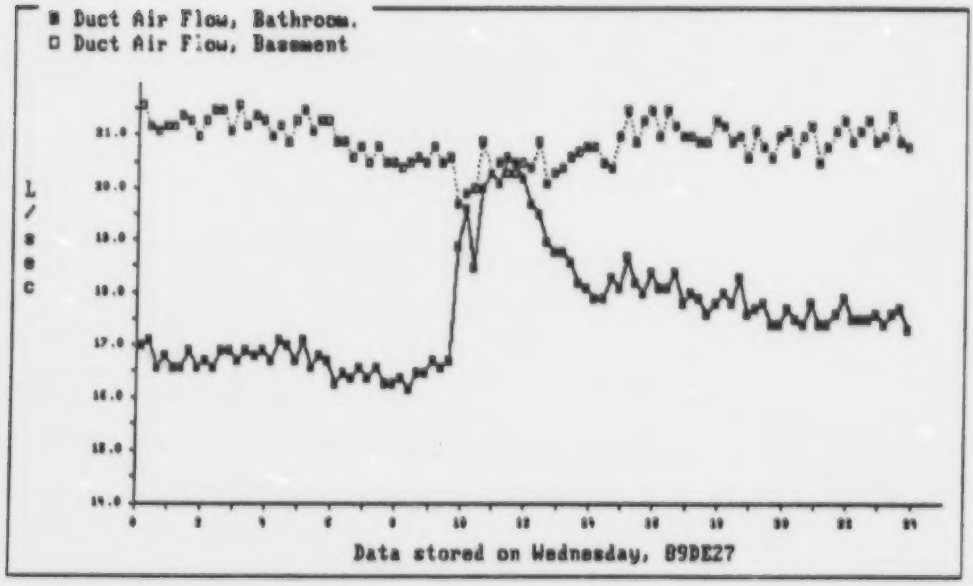
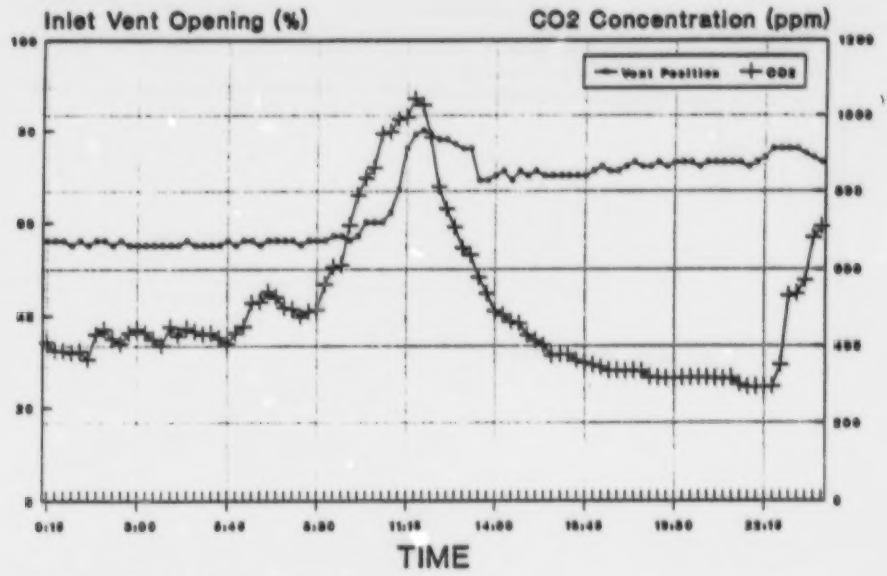
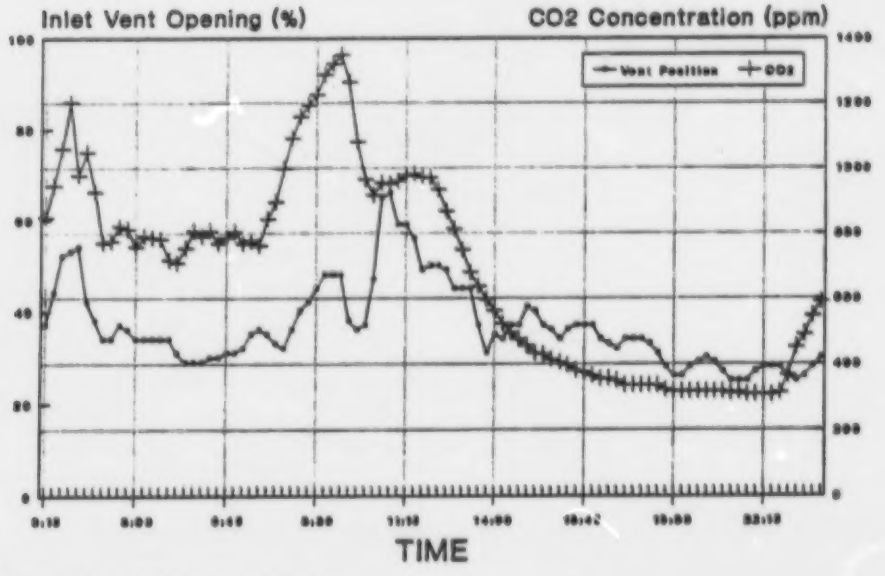


Figure 30: Duct air flow (Morewood)



Dec 27, 1989 - Living room, Morewood

Figure 31: Response of air inlets to occupancy (Morewood)



Dec 27, 1989 - Bed Room, Morewood

Figure 32: Response of air inlets to occupancy (Morewood)

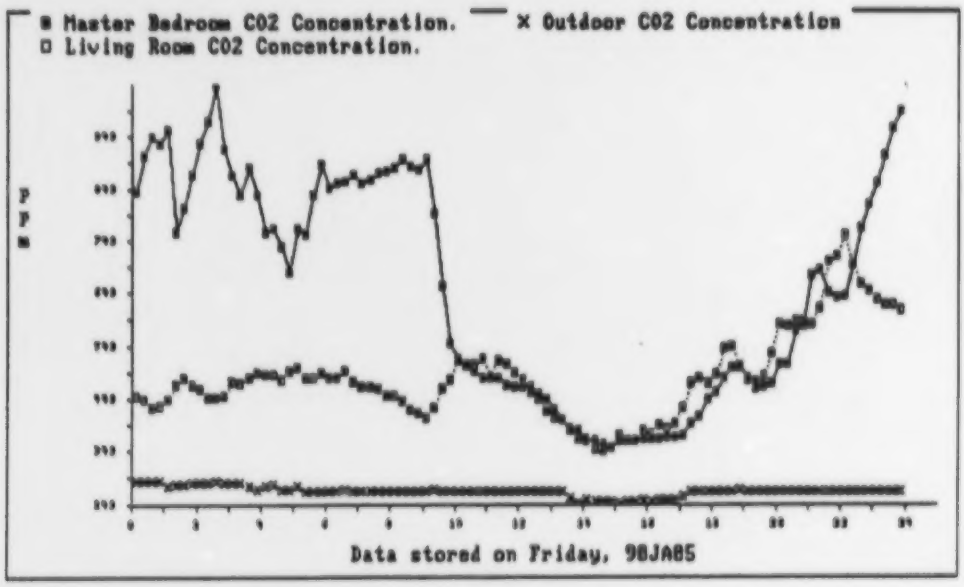


Figure 33: CO_2 variations (Morewood)

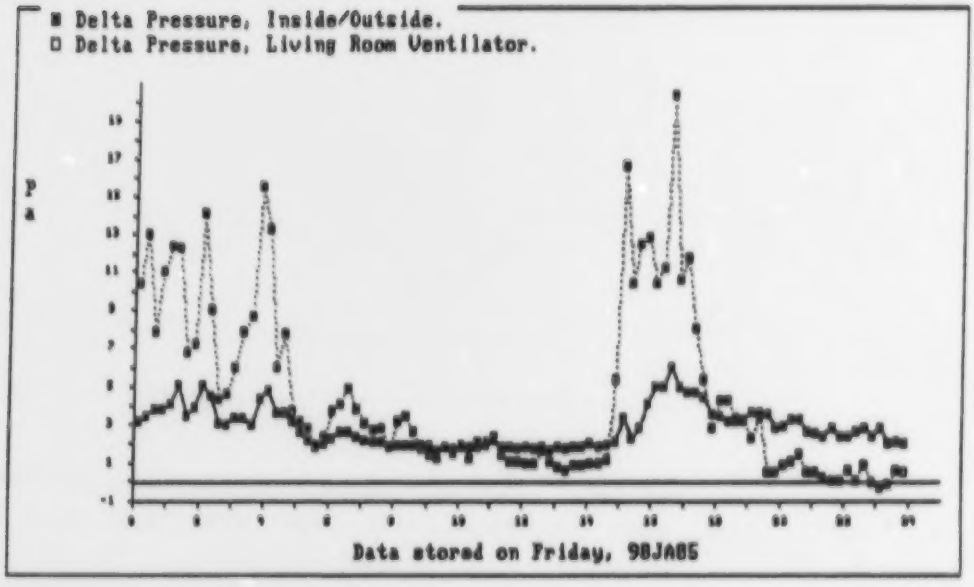


Figure 34: ΔP across living room vent (Morewood)

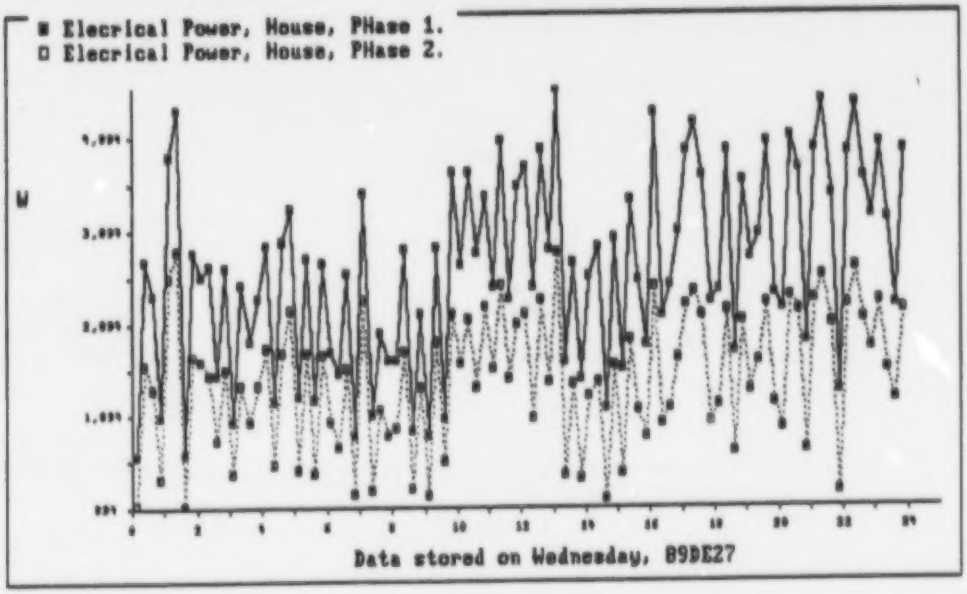
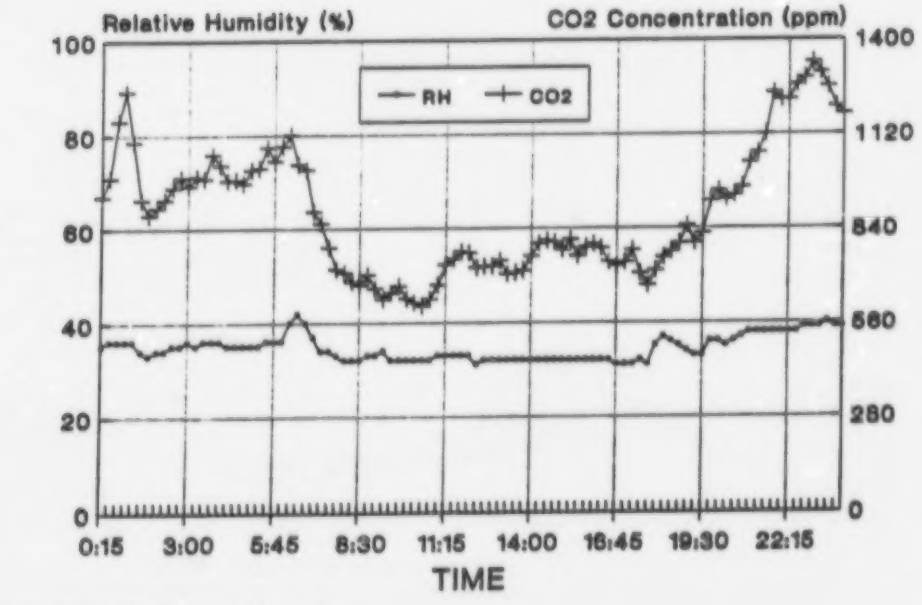
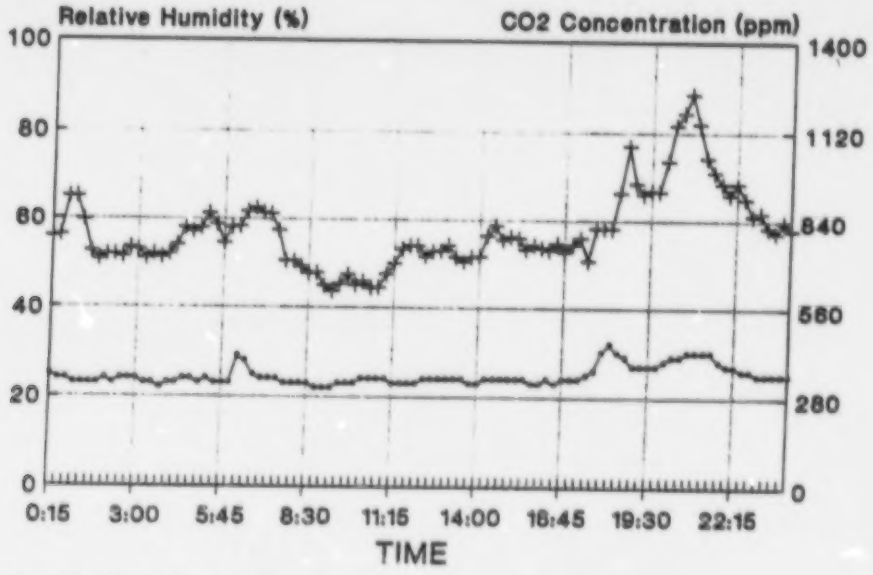


Figure 35: Profile of power consumption (Morewood)



December 15, 1989 - Bedroom

Figure 36: Response of relative humidity to occupancy - Bedroom



December 18, 1989 - living room

Figure 37: Response of relative humidity to occupancy - Living room

APPENDIX A: DESCRIPTION OF HOUSES

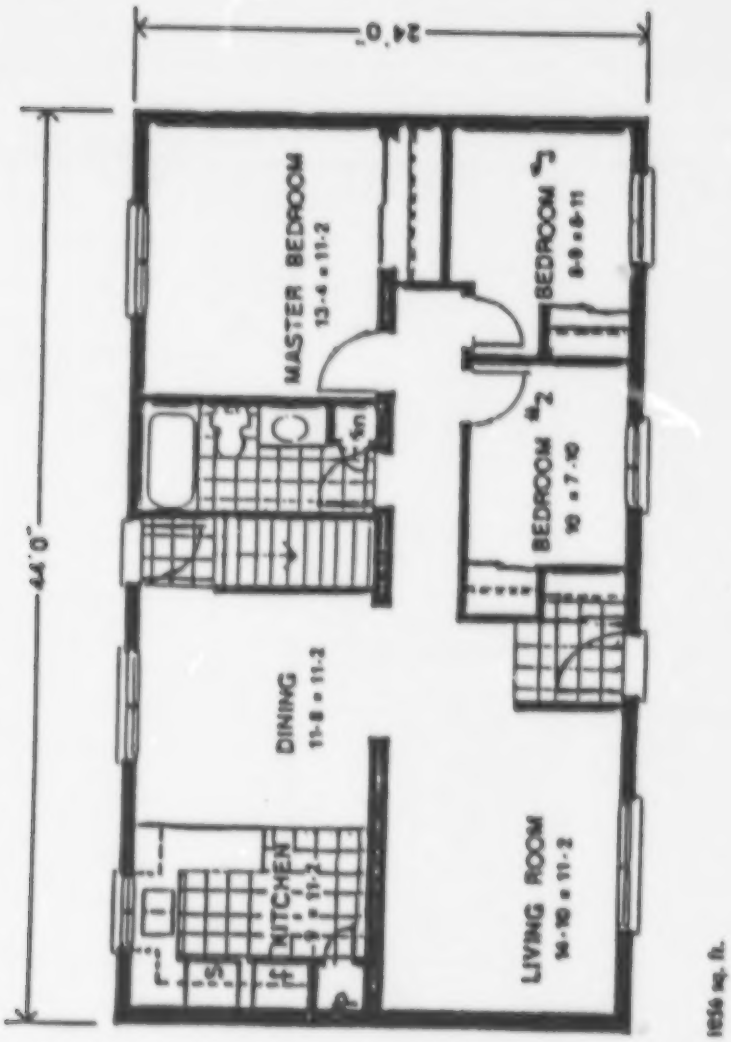


FIGURE 2: House B - Carleton Place

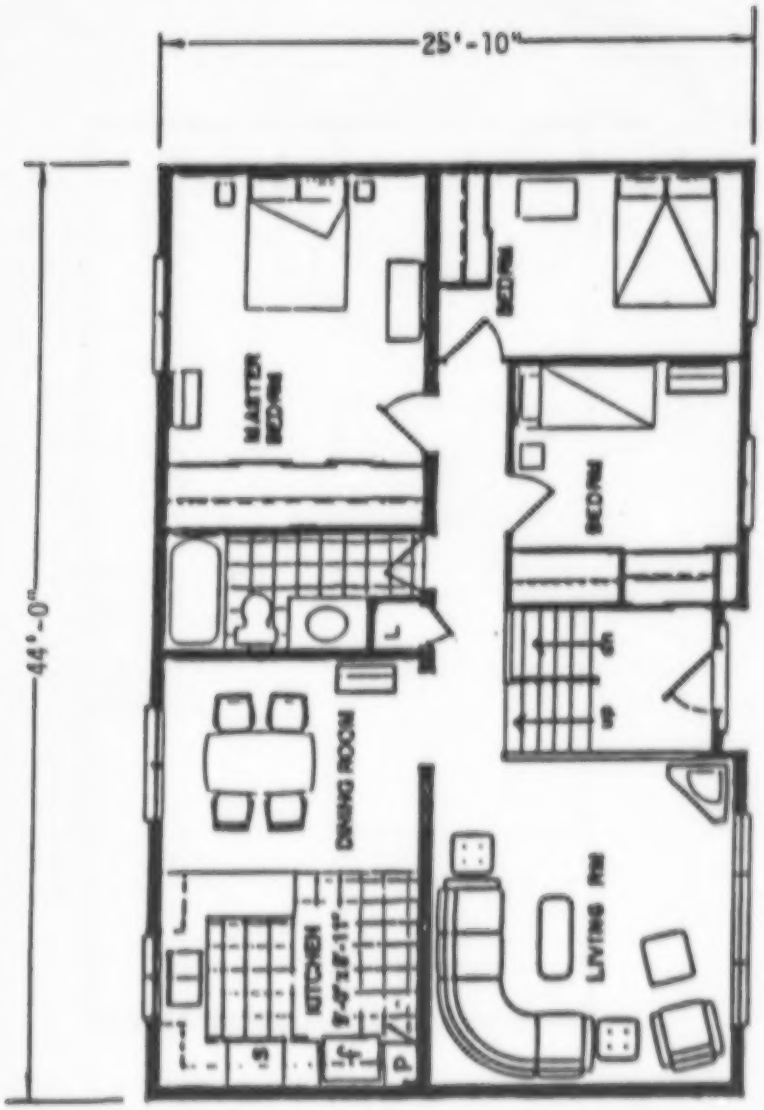
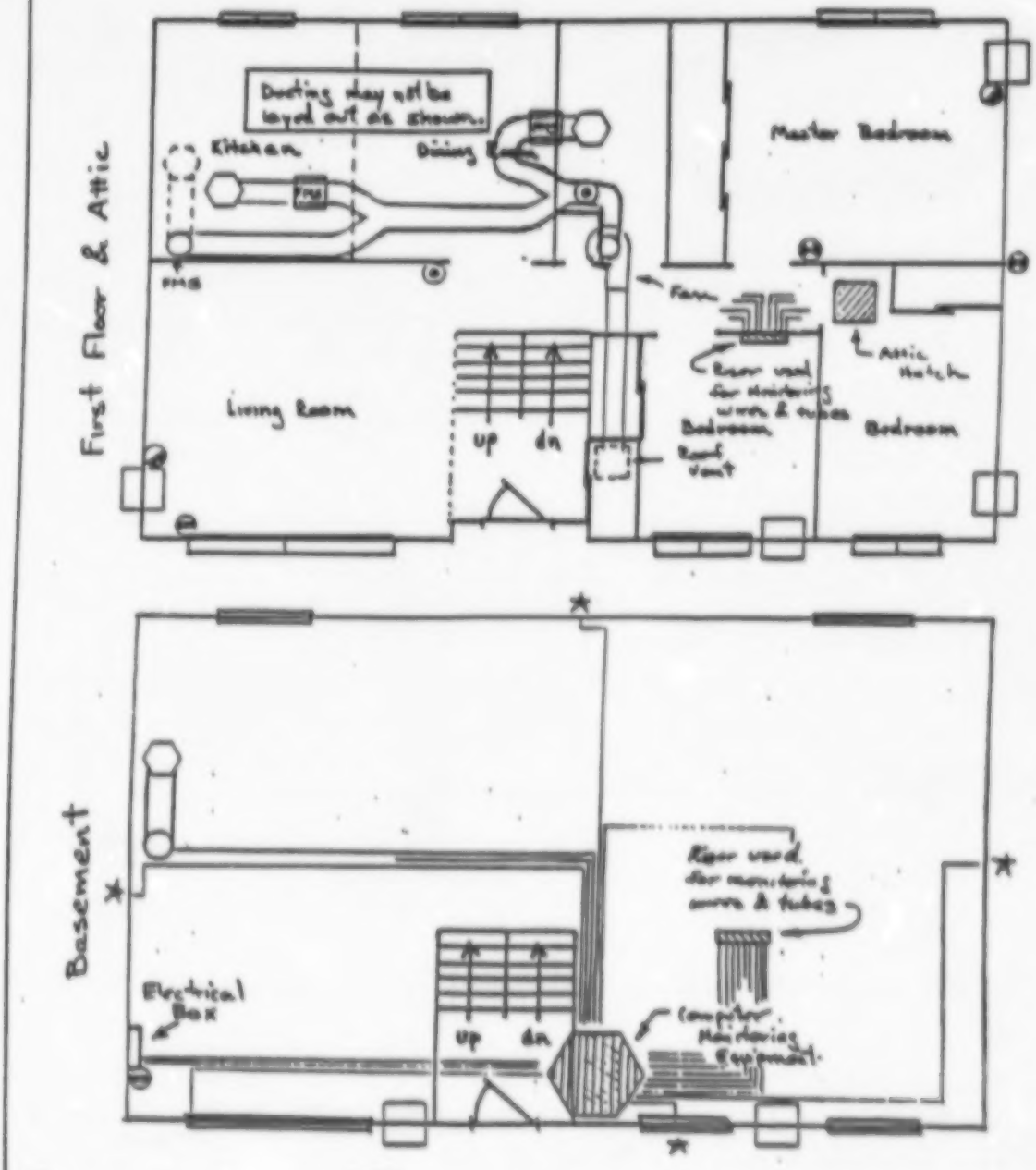


FIGURE 1: House A - Morewood, Ontario

Project: Lot B Alyssa Crescent, Norwood Ont. | By: JKYL | Page of
Date: June 16, 1989
Job No.: S.8923 Job Title: AERECO - Phase I

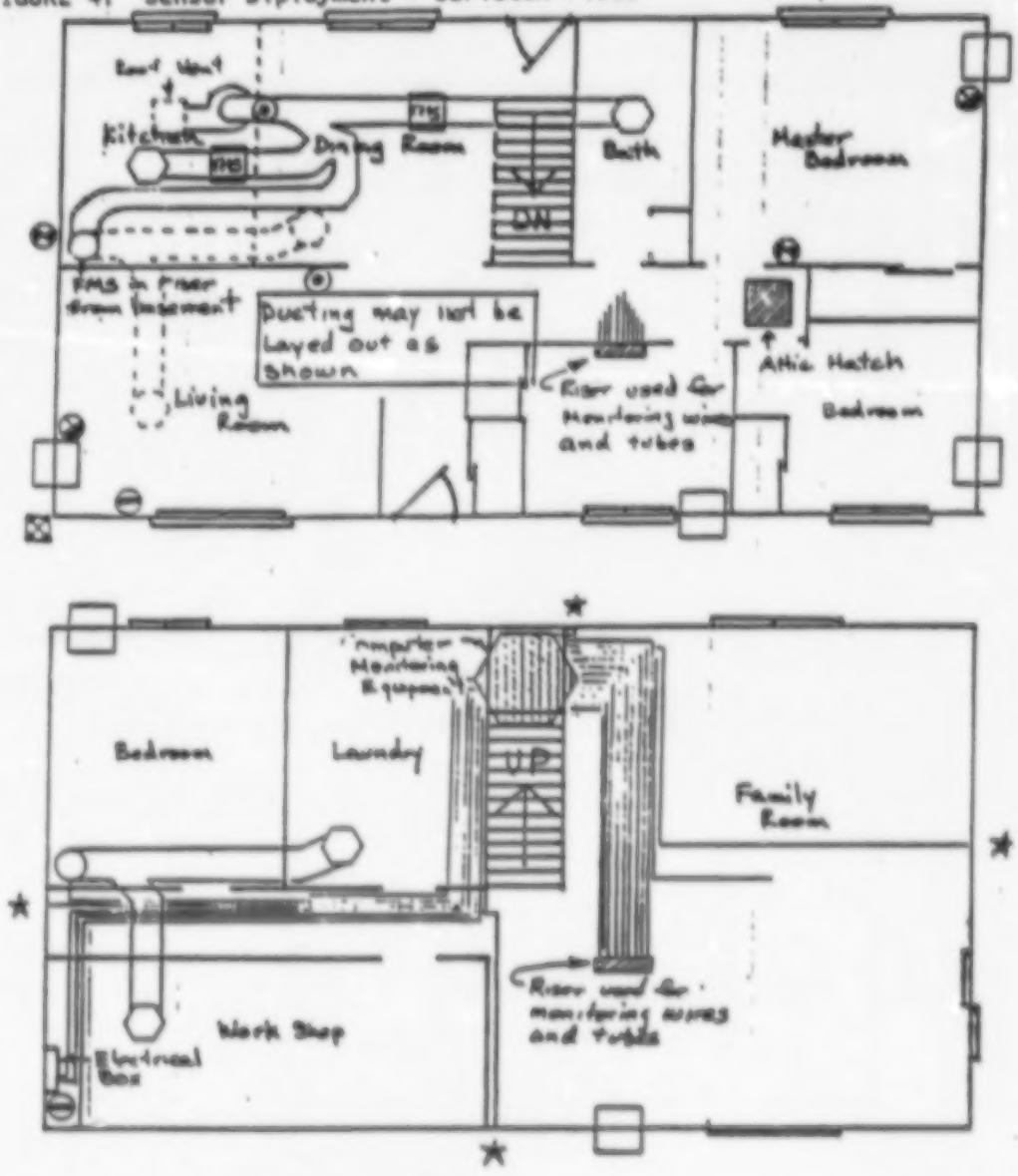
FIGURE 3: Sensor Diployment - Norewood



Project: R.R.#1, Carleton Place, Ontario | By: JRV | Date: Sept. 6, 1989 | Pag of

Job. No.: 5.8923 Job Title: AERECO - Phase I

FIGURE 4: Sensor Diployment - Carleton Place



Exhaust Outlet
Air Inlet
FMS Flow Measuring Station
Windspeed
Ductwork
T, RH, Damper Pos., ΔP
CO_2, T, RH
CO_2, T, RH, Δi
Pressure taps & ΔP_{trans}
Current

AIRTIGHTNESS TEST RESULTS (Before installation of AERECO system)
(AS PER CAN/CGSB - 149.10 - M86)

CRAIG WHEELER (House A - Morewood) JUNE 7,1989
Ext.Temp. = 18 C Wind Speed = 7 km/h
Envelope Area = 390.7 m^2 Volume = 460.2 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	PRESS.(Pa) ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	FLOW(L/S) ADJ'D.	FLOW(L/S) FITTED	RELATIVE ERROR(%)
60.0	60.0	18.0	365.00	365.00	366.53	0.42
55.0	55.0	18.0	341.00	341.00	341.15	0.04
50.0	50.0	18.0	317.00	317.00	315.36	0.52
45.0	45.0	18.0	296.00	296.00	289.11	2.33
40.0	40.0	18.0	256.00	256.00	262.35	2.48
35.0	35.0	18.0	234.00	234.00	235.00	0.43
30.0	30.0	18.0	205.00	205.00	206.94	0.95
25.0	25.0	18.0	176.00	176.00	178.05	1.17
20.0	20.0	18.0	152.00	152.00	148.13	2.55
15.0	15.0	18.0	117.00	117.00	116.84	0.14

C = 12.52244 n = .8246852

E.L.A. = 335.89 cm^2 N.L.A. = 0.860 cm^2/m^2

Q @ 10Pa = 83.63 L/S Q @ 50Pa = 315.36 L/S

Air Change per Hour @ 50Pa = 2.467

SXX= 4.675129E+10 SXY= 3.855509E+10

SYY= 3.187357E+10 SYX= 3.815291

Correlation Coefficient= .9987796

Relative Standard Error = 2.18%

AIRTIGHTNESS TEST RESULTS (AERECO inlets sealed)
(AS PER CAN/CGSB - 149.10 - M86)

SEAL WHEELER (House A - Morewood) 09-06-89
Ext.Temp. = 24 C Wind Speed = 10 km/h
Envelope Area = 390.7 m^2 Volume = 460.2 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa)		TI	FLOW(L/S)			RELATIVE
MEAS'D.	ADJ'D.	(C)	MEAS'D.	ADJ'D.	FITTED	ERROR(%)
60.0	60.0	23.5	386.00	386.33	385.88	0.12
55.0	55.0	23.5	357.00	357.30	359.21	0.53
50.0	50.0	23.5	331.00	331.28	332.10	0.25
45.0	45.0	23.5	305.00	305.26	304.52	0.24
40.0	40.0	23.5	278.00	278.23	276.38	0.67
35.0	35.0	23.5	252.00	252.21	247.61	1.82
30.0	30.0	23.5	212.00	212.18	218.10	2.79
25.0	25.0	23.5	187.00	187.16	187.71	0.30
20.0	20.0	23.5	159.00	159.13	156.21	1.84
15.0	15.0	23.5	121.00	121.10	123.28	1.79

C = 13.26782 n = .823131

E.L.A. = 354.61 cm^2 N.L.A. = 0.908 cm^2/m^2

Q @ 10Pa = 88.29 L/S Q @ 50Pa = 332.10 L/S

Air Change per Hour @ 50Pa = 2.598

SXX= 5.711856E+10 SXY= 4.701605E+10

SYY= 3.875747E+10 SYX= 3.103747

Correlation Coefficient= .9992631

Relative Standard Error = 1.69%

AIRTIGHTNESS TEST RESULTS (AERECO inlets at minimum position)
(AS PER CAN/CGSB - 149.10 - M86)

MIN WHEELER (House A - Morewood) 09-06-89
Ext.Temp. = 23 C Wind Speed = 10 km/h
Envelope Area = 390.7 m^2 Volume = 460.2 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
60.0	60.0	23.5	418.00	417.65	416.64	0.24
55.0	55.0	23.5	386.00	385.67	389.69	1.04
50.0	50.0	23.5	365.00	364.69	362.18	0.69
45.0	45.0	23.5	339.00	338.71	334.01	1.39
40.0	40.0	23.5	299.00	298.75	305.11	2.13
35.0	35.0	23.5	278.00	277.77	275.36	0.87
30.0	30.0	23.5	245.00	244.79	244.61	0.08
25.0	25.0	23.5	212.00	211.82	212.63	0.38
20.0	20.0	23.5	177.00	176.85	179.13	1.29
15.0	15.0	23.5	146.00	145.88	143.61	1.56

C = 17.92896 n = .7683276

E.L.A. = 422.38 cm^2 N.L.A. = 1.081 cm^2/m^2

Q @ 10Pa = 105.17 L/S Q @ 50Pa = 362.18 L/S

Air Change per Hour @ 50Pa = 2.833

SXX= 8.787906E+10 SXY= 6.751991E+10

SYY= 5.197372E+10 SYX= 3.66827

Correlation Coefficient= .999073

Relative Standard Error = 1.76%

AIRTIGHTNESS TEST RESULTS (AERECO inlets at maximum position)
(AS PER CAN/CGSB - 149.10 - M86)

MAX WHEELER (House A - Morewood) 09-06-89
Ext.Temp. = 23 C Wind Speed = 10 km/h
Envelope Area = 390.7 m^2 Volume = 460.2 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
60.0	60.0	23.5	456.00	455.62	462.72	1.56
55.0	55.0	23.5	435.00	434.63	434.65	0.00
50.0	50.0	23.5	409.00	408.66	405.85	0.69
45.0	45.0	23.5	383.00	382.68	376.23	1.68
40.0	40.0	23.5	350.00	349.70	345.67	1.15
35.0	35.0	23.5	313.00	312.74	314.01	0.41
30.0	30.0	23.5	279.00	278.76	281.06	0.82
25.0	25.0	23.5	241.00	240.80	246.51	2.37
20.0	20.0	23.5	217.00	216.82	209.96	3.16
15.0	15.0	23.5	165.00	164.86	170.71	3.55

C = 24.33981 n = .7192897

E.L.A. = 512.19 cm^2 N.L.A. = 1.311 cm^2/m^2

Q @ 10Pa = 127.53 L/S Q @ 50Pa = 405.85 L/S

Air Change per Hour @ 50Pa = 3.175

SXX= 1.460855E+11 SXY= 1.050778E+11

SYY= 7.585399E+10 SYX= 5.467553

Correlation Coefficient= .9982014

Relative Standard Error = 2.28%

AIRTIGHTNESS TEST RESULTS (AERECO inlets sealed)
(AS PER CAN/CGSB - 149.10 - M86)

CALETON-1 (House B - Carleton Pl.) DECEMBER 8, 1989

Ext.Temp. =-10 C Wind Speed = 0 km/h

Envelope Area = 352.4 m^2 Volume = 414.9 m^3

Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
60.0	60.0	17.4	322.00	306.44	305.80	0.21
55.0	55.0	17.8	313.00	297.67	287.22	3.51
50.0	50.0	17.6	274.00	260.67	268.16	2.87
45.0	45.0	17.4	255.00	242.68	248.56	2.42
40.0	40.0	17.3	236.00	224.64	228.34	1.65
35.0	35.0	17.3	217.00	206.55	207.40	0.41
30.0	30.0	17.3	201.00	191.32	185.60	2.99
25.0	25.0	17.3	168.00	159.91	162.76	1.78
20.0	20.0	17.3	143.00	136.11	138.59	1.82
15.0	15.0	17.3	124.00	118.03	112.65	4.56

C = 16.01214 n = .7204081

E.L.A. = 337.82 cm^2 N.L.A. = 0.959 cm^2/m^2

Q @ 10Pa = 84.11 L/S Q @ 50Pa = 268.16 L/S

Air Change per Hour @ 50Pa = 2.327

SXX= 2.8877E+10 SXY= 2.080322E+10

SYY= 1.5132E+10 SYX= 6.042186

Correlation Coefficient= .995191

Relative Standard Error = 3.74%

AIRTIGHTNESS TEST RESULTS (AERECO inlets at minimum position)
(AS PER CAN/CGSB - 149.10 - M86)

CARL-3 (House B - Carleton Place) DECEMBER 8, 1989
Ext.Temp. =-10 C Wind Speed = 0 km/h
Envelope Area = 352.4 m^2 Volume = 414.9 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
60.0	60.0	16.0	365.00	348.20	349.51	0.37
55.0	55.0	16.3	348.00	331.81	327.99	1.15
50.0	50.0	16.2	322.00	307.08	305.93	0.37
45.0	45.0	16.4	305.00	290.76	283.27	2.58
40.0	40.0	16.4	265.00	252.63	259.92	2.89
35.0	35.0	16.6	240.00	228.72	235.77	3.08
30.0	30.0	16.7	218.00	207.72	210.66	1.42
25.0	25.0	16.8	190.00	181.01	184.40	1.87
20.0	20.0	16.8	164.00	156.24	156.67	0.27
15.0	15.0	16.8	143.00	136.23	126.98	6.79

C = 17.56764 n = .7303906

E.L.A. = 379.25 cm^2 N.L.A. = 1.076 cm^2/m^2

Q @ 10Pa = 94.43 L/S Q @ 50Pa = 305.93 L/S

Air Change per Hour @ 50Pa = 2.655

SXX= 4.845994E+10 SXY= 3.539468E+10

SYY= 2.604034E+10 SYX= 6.041488

Correlation Coefficient= .9963761

Relative Standard Error = 3.30%

AIRTIGHETNESS TEST RESULTS (AERECO inlets at maximum position)
(AS PER CAN/CGSB - 149.10 - M86)

CARL-2 (House 8 - Carleton Place) DECEMBER 8, 1989
Ext.Temp. =-10 C Wind Speed = 0 km/h
Envelope Area = 352.4 m^2 Volume = 414.9 m^3
Pressure With Fan Sealed - Start: 0 Pa Finish: 0 Pa

PRESS.(Pa) MEAS'D.	ADJ'D.	TI (C)	FLOW(L/S) MEAS'D.	ADJ'D.	FITTED	RELATIVE ERROR(%)
60.0	60.0	16.5	418.00	398.42	399.41	0.25
55.0	55.0	16.5	390.00	371.73	374.56	0.76
50.0	50.0	16.5	379.00	361.25	349.11	3.36
45.0	45.0	16.5	351.00	334.56	322.99	3.46
40.0	40.0	16.5	294.00	280.23	296.09	5.66
35.0	35.0	16.6	271.00	258.26	268.29	3.88
30.0	30.0	16.6	241.00	229.67	239.43	4.25
25.0	25.0	16.6	219.00	208.71	209.28	0.27
20.0	20.0	16.6	190.00	181.07	177.49	1.98
15.0	15.0	16.7	161.00	153.41	143.53	6.44

C = 19.43809 n = .7382771

E.L.A. = 427.32 cm^2 N.L.A. = 1.213 cm^2/m^2

Q @ 10Pa = 106.40 L/S Q @ 50Pa = 349.11 L/S

Air Change per Hour @ 50Pa = 3.029

SXX= 8.153098E+10 SXY= 6.019246E+10

SYY= 4.514539E+10 SYX= 10.27186

Correlation Coefficient= .9921425

Relative Standard Error = 4.93%

APPENDIX B: INSTALLATION AND CALIBRATION OF MONITORING SYSTEM

Protocol - Monthly Site Visit(s)

Homeowner Survey

- collect consumer log book.
- question homeowner on unusual recollections and/or complete monthly log.
- obtain homeowner opinions/impressions regarding operation of AERECO system.

Monitoring/Testing

- inspect all AERECO inlets and exhausts. Record approximate open position. Quantify between 0-100%.
- read and record electrical metre.
- record window condensation, if any.
- check outdoor wind speed.
- measure and record RH, temperature, and CO_2 (Gastec) at all sensor locations including outdoors. At outdoor location, approximate wind speed and direction.
- record simultaneous sensor results (from monitor screen) for RH, temperature and CO_2 for correlation with manual measurements.
- in basement, take radon measurements.

Note: On three of the monthly visits (December 1, February 1 and April 1), install AQR PF-1 Formaldehyde Dosimeters.

SCIEMETRIC
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FINAL REPORT

INSTALLATION, COMMISSIONING & MAINTENANCE FOR THE AERECO VENTILATION EQUIPPED HOUSES IN MOREWOOD & CARLETON PLACE, ONTARIO

Since June of 1989, Sciemetric has worked with Scanada Consultants Ltd., on the monitoring of two houses equipped with the Aereco demand controlled ventilation systems. This report summarizes this work, with particular emphasis on sensor calibrations, and manual kWh readings.

I. MOREWOOD.

Data collection was begun at the Morewood house on 19 June, 1989. The following calibrations were performed:

1. The Living Room Vent Position was calibrated as follows: The magnet and Hall effect transducer in the vent produce a voltage which varies with position as follows:

Position	Voltage
Closed	0.745 0.747
Open	0.778 0.776
60% Open	0.768 0.770
10% Open	0.746 0.747

These points were fit to the following equation, which yields a reasonably good fit:

$$\% \text{ Open} = (V - 0.745) / 0.00032.$$

2. The Master Bedroom Vent Position was calibrated as follows:

Position	Voltage
Closed	0.715 0.715
Open	0.746 0.745
60% Open	0.737 0.737
10% Open	0.715 0.715

These points were fit to the following equation, which yields a reasonably good fit:

% Open = (V - 0.715) / 0.00030.

As explained in Sciemetric's letter of 22 June, 1989, the voltage divider used with the vent position provided a poor match for the Model 161's scales. These were changed, and the vent positions were recalibrated on 18 December, 1989.

3. The Temperature and Relative Humidity Sensors were calibrated against a whirling psychrometer, with the following results. (Readings from the PILOT screen were taken before and after the psychrometer readings to check for changes in conditions):

Living Room:

PILOT Readings:	T = 24.5 C, RH = 54.0 %.
Psychrometer:	Td = 24.5 C Tw = 18.5 C RH = 56.5 %.
PILOT:	T = 24.6 C RH = 55.1 %.

Bedroom:

PILOT:	T = 25.1 C, RH = 64 %.
Psychrometer:	Td = 24.5 C, Tw = 19.0 C, RH = 59 %.
PILOT:	T = 25.2 C, RH = 64 %.

Outdoors:

PILOT:	T = 28.8 C, RH = 52 %.
Psychrometer:	Td = 25.0 C, Tw = 19.0 C, RH = 57 %.
PILOT:	T = 28.5 C. RH = 52 %.

The readings for the Living and Bedrooms agree to well within the accuracies of the instruments used. However, PILOT's outdoor temperature reading is high, apparently because it was affected by air leaving the attic. The outdoor sensors were moved on 18 December, 1989.

Much data was lost at Morewood between August and December, 1989 due to problems with the equipment. It appears that the system must have been struck by lightening at some point, because many chips on five separate pieces of equipment were burned out. On 18 December, 1989 the monitoring system at Morewood was extensively revised, and reactivated. A wind speed sensor (anemometer) was added, the voltage dividers on the vent position sensors were changed, the ambient sensors were moved, and a telephone line and modem communications package were added. The following calibrations were performed:

1. The Bedroom Room Vent Position:

Position	Voltage
100% Open	4.2041 4.2100
0% Open	4.0356 4.0479
25% Open	4.060
50% Open	4.1040 4.1162
75% Open	4.1620 4.166
90% Open	4.1858 4.1895
10% Open	4.0369 4.048
0% Open	4.0479
100% Open	4.2065 4.2100

The following linear formula which gives an approximate fit is used in the PILOT Task:

%Open = (V - 4.048) * 617.3

2. The Living Room Vent Position:

Position	Voltage
100% Open	4.2578 4.2578
0% Open	4.0833 4.083

The following linear formula is used in the PILOT Task:

%Open = (V - 4.0833) * 573.1

3. The House Electrical Power, Phase 1:

PILOT (W)	AMMETER (A)	AMMETER (W @ 120 V)
1628	14.0	1680
2293	19.8	2376
2773	23.9	2868
3421	29.0	3480
4499	37.0	4440
6755	57.0	6840
9146	75.0	9000
1751	15.0	1800
1157	9.6	1152

These results agree within the accuracy of the two instruments.

4. The House Electrical Power, Phase 1:

PILOT (W)	AMMETER (A)	AMMETER (W @ 120 V)
0	0.0	0
605	5.75	690
1003	9.0	1080
1564	15.8	1896
2498	24.2	2904
3928	37.3	4476
5164	58.0	6960
8007	74.0	8880
5415	11.5	6240

This calibration shows that the PILOT was consistently low, and the average error was 14.4%. The equation in PILOT was corrected, but it now appears that the correction factor was done inversely, thus increasing the error. The PILOT equation corresponding to this element should be (Etot2>0.003)*(Etot2*41331.0), but is probably (Etot2>0.003)*(Etot2*30320.0). If this is true, then all the recorded values for House Electric Power, Phase 2 should be multiplied by 1.363.

At the time of this site visit, the electric power of the house was being used for heat and lighting in the house next door.

Data collection was begun at 1508 EST, and the house meter reading was 1185.0 X 10 kWh.

At some point in early February, it was noticed that the data collected through the Scanivalve had become increasingly

unreliable and then missing completely. This data includes the CO2 levels, the air flows, and the pressure differences. The Relative Humidity in the Attic Duct was reading close to 0%, indicating a problem with the sensor. On 2 March, 1990 Sciemetric visited the house and replaced the duct RH sensor, but found that the Scanivalve had burned out. The system was left running, but the scanivalve data is invalid until 21 March, 1990. The system was restarted at 1542 EST, and the house meter was read as 2079 X 10 kWh. The following calibrations were made:

1. Temperature and Relative Humidity:

Living Room:		
	PILOT Readings:	T = 19.8 C, RH = 40.5 %.
	Psychrometer:	Td = 20.0 C Tw = 13.0 C RH = 44.0 %.
	PILOT:	T = 19.8 C RH = 37.2 %.
Bedroom:		
	PILOT:	T = 20.6 C, RH = 36.7%.
	Psychrometer:	Td = 21.0 C, Tw = 14.0 C, RH = 46 %.
	PILOT:	T = 20.5 C, RH = 36.1 %.
Outdoors:		
	PILOT:	T = 4.3 C, RH = 27.6 %.
	Psychrometer:	Td = 3.0 C, Tw = 0.0 C, RH = 54 %.
	PILOT:	T = 4.5 C. RH = 27.3 %.

The Living Room and Bedroom readings agree within the accuracy of the instruments involved. The discrepancy of the outdoor reading may be due to the loss of accuracy of both the RH sensor and the psychrometer at low temperatures.

On 21 March, 1990 Sciemetric visited the house again and changed the burned out part of the scanivalve. Data collection was

stopped at 1115 EST, and the house meter was read as 2243.1 X 10 kWh. Data collection began again at 1431 EST and the house meter was read as 2244.3 X 10 kWh. All sensors appeared to be operating normally.

II. CARLETON PLACE.

Data collection at the Carleton Place house was begun on 16 November, 1989 at 1915 EST, and the house meter reading was 0403.2 kWh. The following calibrations were made on that date:

1. House Electric Power, Phase I:

PILOT	AMMETER	
(W)	(A)	(W @ 120 V)
818	6.2	744
1480	11.9	1428
1857	15.0	1800
2552	21.5	2580
3591	29.7	3564
799	6.5	780

2. House Electric Power, Phase II:

PILOT	AMMETER	
(W)	(A)	(W @ 120 V)
695	5.6	672
773	6.4	768
1071	8.6	1032
1760	14.5	1740
2838	24.0	2880
3870	32.0	3840
766	6.4	768

All of the electrical power calibrations are well within the accuracy of the instruments used.

3. Temperature and Relative Humidity:

Living Room at Thermostat:

PILOT: T = 21.2 C,
RH = 35.3 %.

Psychrometer: Td = 21.0 C,
Tw = 14.0 C,
RH = 44 %

PILOT: T = 21.2 C,
RH = 35.5 %.

Living Room at Vent:

PILOT:	T = 21.1 C, RH = 48.8 %.
Psychrometer:	Td = 21.0 C, Tw = 14.0 C, RH - 44 %.
PILOT:	T = 21.2 C, RH = 51.8 %.

Bedroom:

PILOT:	RH = 43.7 %.
Psychrometer:	Td = 20.5 C, Tw = 13.5 C, RH = 45 %.
PILOT:	T = 20.8 C, RH = 42.6 %.

Outdoors:

PILOT:	T = 3.3 C, RH = 62.1 %.
Psychrometer:	Td = 4.0 C, Tw = 1.5 C, RH = 63 %.
PILOT:	T = 3.1 C, RH = 61.5 %.

These calibrations are within the accuracies of the instruments used, except that PILOT's readings at the Living Room Thermostat may be low.

4. Bedroom Vent Position.

Position (% Open)	Voltage
100	4.091
0	3.983
25	3.988
50	4.010
75	4.060
100	4.114
0	3.980

The following linear equation gave an approximate fit:

$$\% \text{ Open} = (V - 3.98) * 769.23.$$

However, we found that both the bedroom and living room vents were prevented from closing fully because the magnets and hall effect transducers had been placed incorrectly. These were replaced on 8 December, 1989.

On 7 December, 1989 we visited the site and found that the system was hung, apparently due to a problem with the data disk. The last data to be successfully written was at 1530 EST on 2 December, 1989.

On 8 December, 1989 the data collection system was restarted at 1553 EST, and the house hydro meter reading was 0705.3 kWh. The vent positions were calibrated as follows:

1. Living Room Vent Position:

Position (% Open)	Voltage
0	4.7559
0	4.7571
100	4.5105
50	4.5837
25	4.6509
75	4.5593
90	4.5227
10	4.6594
0	4.7559
100	4.5166

The following linear formula gives an approximate fit:

% Open = (V - 4.7559) * -412.62.

2. Bedroom Vent Position:

Position (% Open)	Voltage
0	4.9597
100	4.5459
50	4.6826
25	4.7559
75	4.6375
90	4.5984
10	4.8743
0	4.9525
100	4.5483

The following linear formula gives an approximate fit:

% Open = (V - 4.956) * -244.49.

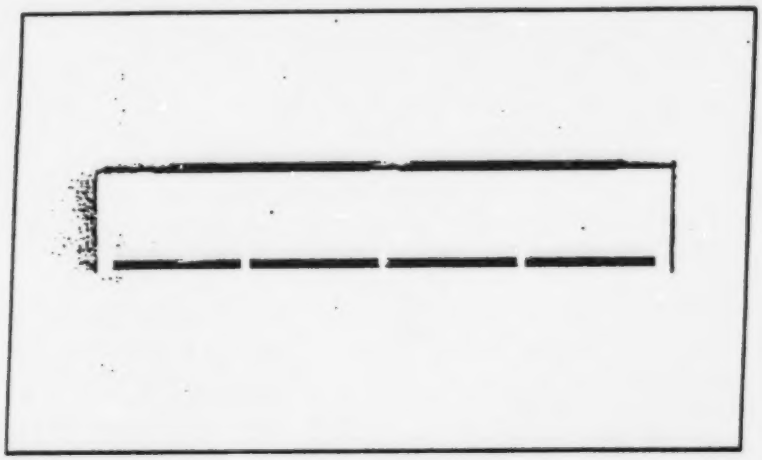
The last site visit to the Carleton Place house was made on 13 December, 1989. The system was shut down just after 1200 EST, and the house meter was read as 0775.8 kWh. Various attempts were made to correct inconsistencies in the air flow and pressure difference readings without much success. We found that the tube which takes CO2 from the duct in the attic was blocked by ice. We suspect that condensation and icing occurred in many of the tubes used to measure pressure differences and flows. It also seems that the pressure transducers used in the two Aereco houses are not sufficiently accurate for these purposes.

The data collection system was restarted on 13 December, 1989 at 1338 EST, and the house hydro meter was read as 0776.8 kWh.

APPENDIX C: AERECO HUMIDITY-CONTROLLED VENTILATION SYSTEM

Humidity-controlled air inlet

PATENTED



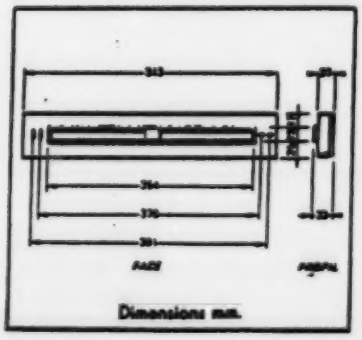
The humidity-controlled air inlet AERECO is the component of the humidity-controlled ventilation system allowing to distribute the incoming fresh air in each main room, according to their respective humidity.

It can only be used, in a new dwelling, in a compiete humidity-controlled system including a special fan and humidity-controlled extract units.

I. DESCRIPTION

The humidity-controlled air inlet is composed of :

- a humidity sensor composed of 8 nylon strips set in an inox case ;
- a plastic front-part (colour beige) ;
- a plastic base (colour brown) ;
- a caulking-joint located on the back part of the base ;
- an actuator ;
- 2 shutters allowing to modify the opening section (from 5 cm^2 to 30 cm^2) ;
- 2 positions : ● and + ;
- weight of the air inlet : 0,250 kg.



II. FUNCTIONING

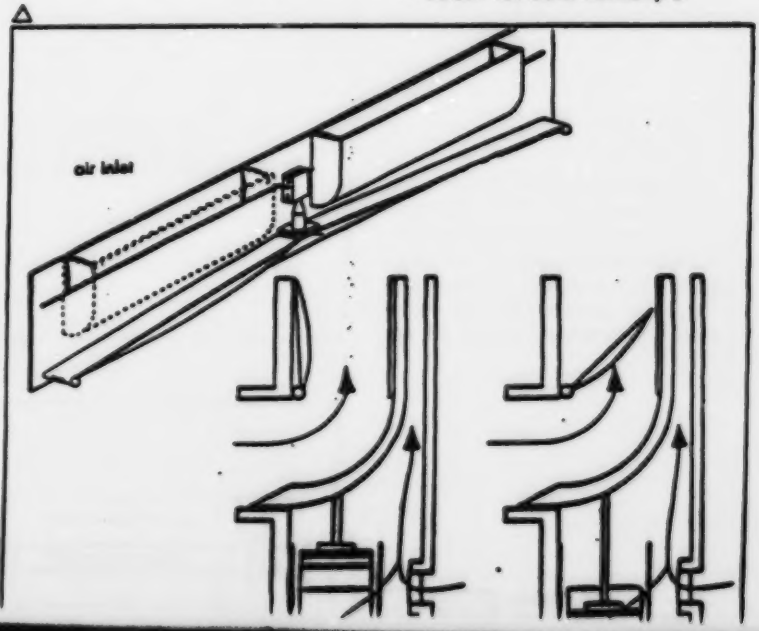
The functioning of the system is based on the physical reactions of a reader of humidity which is composed of a polyamid tissue stretching or shrinking as function of the humidity rate. The movements of the tissue are amplified and transmitted by a system of actuator to the movable shutter.

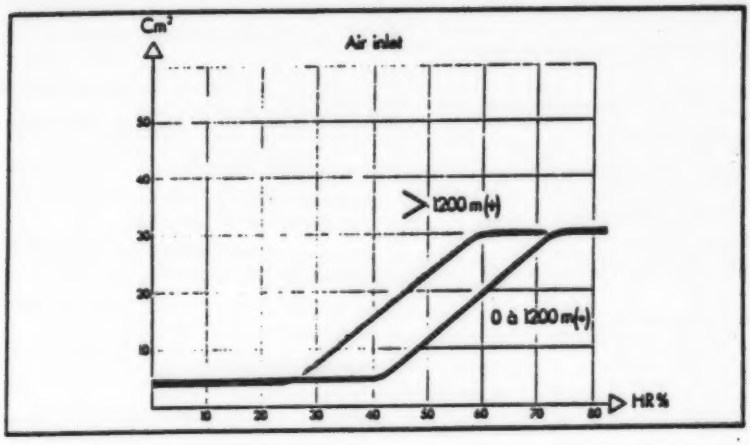
The humidity-controlled air inlet allows to change the opening section from 5 cm^2 till 30 cm^2 according to the humidity rate of the room where it is. The opening section is :●

- 5 cm^2 for 40 % humidity ;
- 30 cm^2 for 75 % humidity.

With the position signed +, the opening section is :

- 5 cm^2 for 25 % humidity ;
- 30 cm^2 for 60 % humidity. ▷





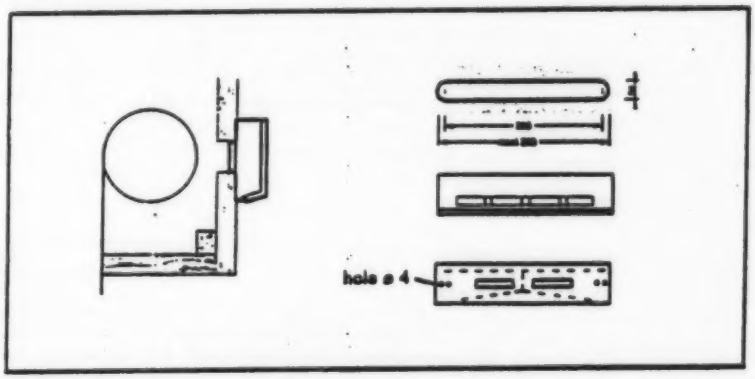
The humidity-controlled air inlets are shaped so that they are able to meet an eventual increase of the pressure-difference in the dwelling reaching eventually 40 pascals (0.16 ins.wg), maintaining a quiet functioning.

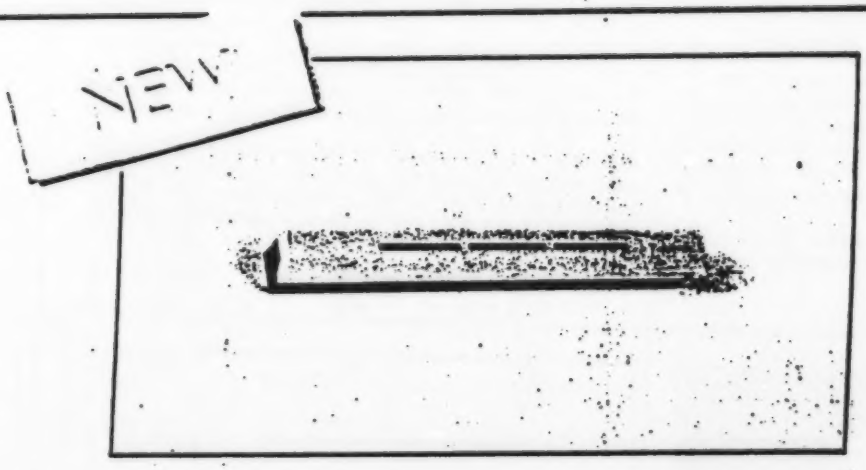
The nylon strips are protected from the outside air coming into the air inlet, so that the only ambient air will act on them; so the inside humidity of the dwelling will set them in motion.

III. INSTALLATION

In order to prevent a wrong reading of the humidity, it is necessary to avoid installing the humidity-controlled air inlets above an heater.

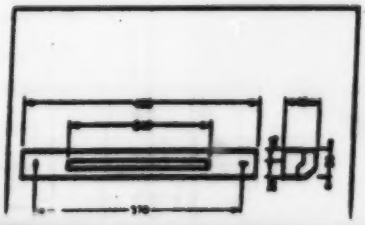
The humidity-controlled air inlet can be installed:
1 - in the frame of rolling shutter; ▷
2 - wall-mounted;
3 - above the window;
4 - in the attics (for single-family houses).





The new humidity-controlled air inlet of AERECO, instead of being wall-mounted, can be installed on the window-frame in the living and bedrooms; it works according to the same principle as the above-mentioned air inlet.

DESCRIPTION –
- a humidity sensor composed of 8 nylon strips –
- a plastic front-part (colour beige) –
- a plastic base (colour brown) –
- 1 shutter –
- a deflector –



AERECO

B.N.C.

HUMIDITY CONTROLLED
AIR EXHAUSTER

AERECO

OPERATING PRINCIPLE OF THE AERECO VENTILATION SYSTEM

In a dwelling, air circulates from the main rooms to the technical rooms in order to prevent odors and excess relative humidity generated by the technical rooms from lowering the quality of air in the main rooms.

The AERECO humidity-controlled ventilation system reduces the pollution level by modifying the airflow according to individual room requirements.

stale air is extracted from the technical rooms (Kitchens, bathrooms, toilets) via a humidity-controlled extraction outlet (BNG) which automatically adjusts its flow to the relative humidity of the room where it is installed.

To replace the stale air, fresh air is ducted into the main rooms (bedrooms, living-room, dining-room ...) via the humidity-controlled air inlets (EMH or EAH) which automatically modify the size of the opening in proportion to the relative humidity of the room where it is fitted - the higher the relative humidity, the greater the opening. in this way, the overall air flow circulating in the home is distributed depending on the relative humidity in each room.

PERFORMANCE OF THE AERECO SYSTEM

1. Sharp reduction in condensation, in particular where mold and odors are likely.
2. Optimal air flows crossing the dwelling, thus eliminating over-drying and excessive energy cost.
3. Energy savings (compared to a constant airflow system) thus amortizing the investment over a short period.
4. Quiet, discreet operation (30 DbA in bathrooms and 35 DbA in the kitchen).
5. Automatic control - no occupant intervention required.
6. Minimal component maintenance
7. Easy installation, not cumbersome.
8. No current supply required
9. Simple and reliable principle (humidity sensor does not disadjust over time).

FUNCTION

Controls the quality of the air in bathrooms, kitchens, and other technical rooms (laundry room, storeroom ...). Reduces mold and odor-generating condensations.

DESCRIPTION

The AERECO relative humidity sensor is composed of 8 nylon strips, each with the same mechanical characteristics, assembled by a simple and reliable AERECO process.
The sensor's role is to detect any variation in relative humidity in the ambient air, thanks to the intrinsic elongation property of nylon.
The information received by the sensor is then passed on to a pneumatic system, a membrane being the major component. This membrane, situated in the air flow channel of the BNG extraction outlet, varies in volume, thus optimizing the airflow required to ventilate the dwelling. This prevents excess room humidity or useless, costly dryness.
The air quality is therefore automatically controlled. The polluted air is evacuated by the BNG unit via the dwelling extraction network.

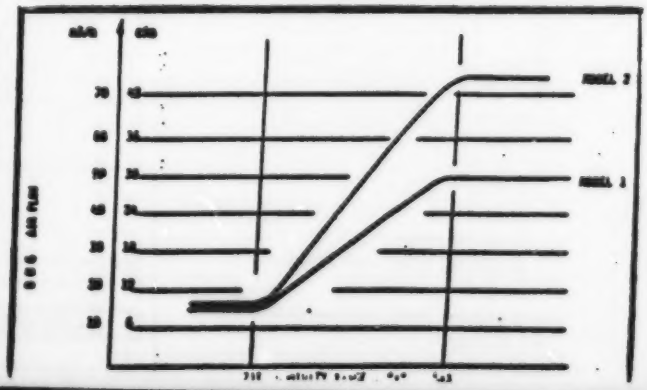
INCREASED AIR FLOW FUNCTION

In some rooms, especially in the kitchen, the pollutants given off are strong and punctual. That is why AERECO also offers the occupant a remote control mechanism allowing him to evacuate the odors quickly.
This quiet, discreet system is built into the BNG extraction outlet. By pressing the pneumatic button the shutter opens allowing an increased flow of 140 m^3/h for 90 minutes. Once the pollutants have been evacuated, the BNG unit automatically returns to its initial position.

CHARACTERISTICS AND SETTINGS

The AERECO BNG unit has various settings in order to adapt it to different types of dwellings, climatic conditions and occupant life-styles.
The system is pre-programmed for two ventilation ranges, the first going from 23 % to 58 % relative humidity ("+"), the second from 35 % to 70 % (".."). The occupant can select the "+" or "." settings indicated on the front. The choice is determined as follows:

setting	thermal bridge	climate
"." (35 %-70 %)	small	temperate
"+" (23 %-58 %	wide	cold



RANGES OF HUMIDITY-CONTROLLED AIR FLOWS :

- model 1 15 m³/h ... 50 m³/h (9 CFM ... 30 CFM)
- model 2 20 m³/h ... 75 m³/h (12 CFM ... 45 CFM)

Weight : 370 g.
Size : 198 mm x 186 mm x 35 mm (7"3/4 x 7"1/3 x 1"1/3)

INSTALLATION AND MAINTENANCE

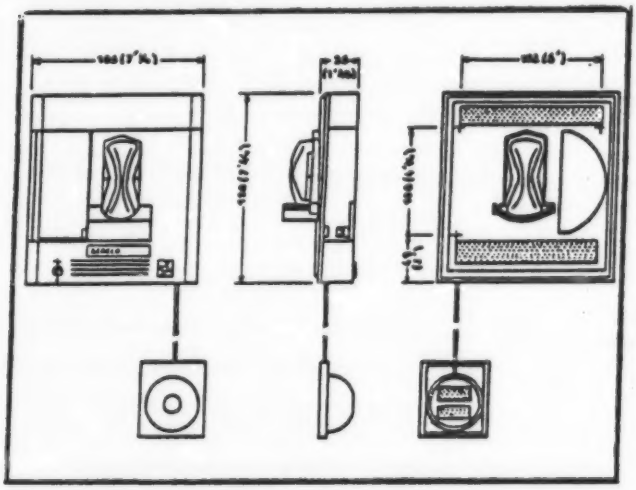
The AERECO BNG unit requires no current supply. Its mounting system can be adapted to any type of support using either fastening strips (VELCRO type on plaster, cement, wood ...) or screws (on moldings, damaged supports ...)

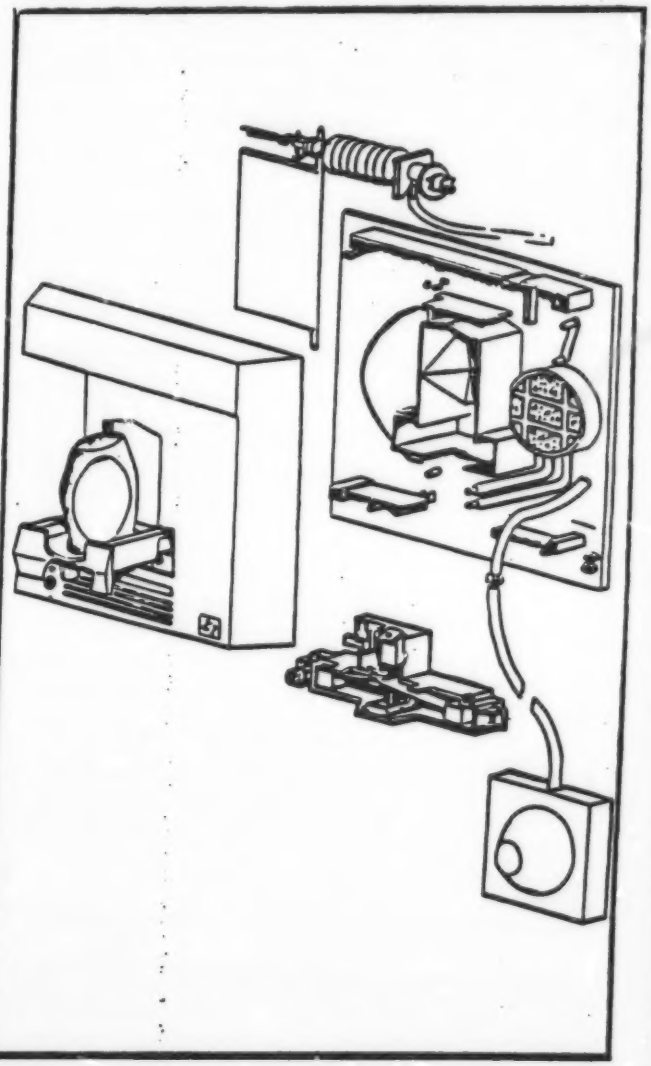
The BNG unit can be fitted on walls or ceilings, near the source of pollution. It must however be easily accessible.

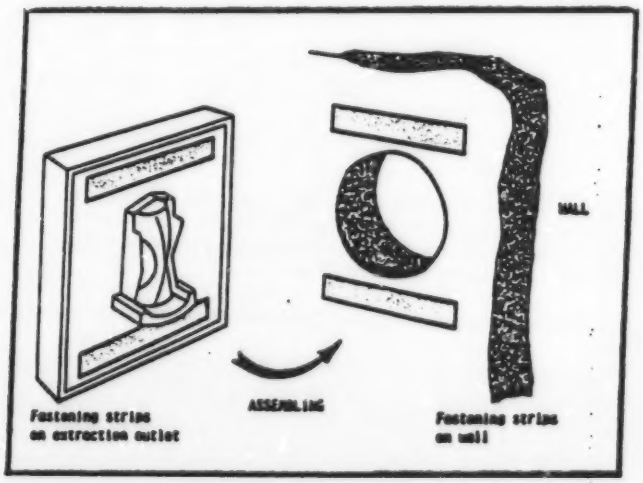
For the BNG unit and the whole AERECO ventilation system to function properly, it must be well installed. Therefore the fastening strips must be adequately fixed (primary glue or staples) and the air tightness between the **BNG** unit and the support ensured.

The pneumatic command and the tube connecting it to the **BNG** unit can either be built-in or surface-mounted up to 7 meters away. The tube should not be twisted, blocked or folded.

Under normal conditions, the apparatus should be checked every three months. Only the central part that is in contact with the polluted air needs to be cleaned and as it is removable, maintenance is simplicity itself.







AERECO

E.M.H.-E.A.H.

HUMIDITY CONTROLLED AIR INLET

AERECO

OPERATING PRINCIPLE OF THE AERECO VENTILATION SYSTEM

In a dwelling, air circulates from the main rooms to the technical rooms in order to prevent odors and excess relative humidity generated by the technical rooms lowering the quality of air in the main rooms.

The AERECO humidity-controlled ventilation system reduces the pollution level by modifying the airflow according to individual room requirements.

Stale air is extracted from the technical rooms (kitchens, bathrooms toilets) via a humidity-controlled extraction outlet (BNG) which automatically adjusts its flow to the relative humidity of the room where it is installed.

To replace the stale air, fresh air is ducted into the main rooms (bedrooms, living-room, dining-room ...) via the humidity-controlled air inlets (EMH or EAH) which automatically modify the size of the opening in proportion to the relative humidity of the room where it is fitted - the higher the relative humidity, the greater the opening. In this way, the overall airflow circulating in the home is distributed depending on the relative humidity in each room.

PERFORMANCE OF THE AERECO SYSTEM

1. Sharp reduction in condensation, in particular where mold and odors are likely.
2. Optimal airflows crossing the dwelling, thus eliminating overdrying and excessive energy cost.
3. Energy savings (compared to a constant air flow system) thus amortizing the investment over a short period
4. Quiet, discreet operation (30 DbA in bathrooms and 35 DbA in the kitchen).
5. Automatic control - no occupant intervention required.
6. Minimal component maintenance.
7. Easy installation, not cumbersome.
8. Not current supply required.
9. Simple and reliable principle (humidity sensor does not disjust over time).

FUNCTION

Automatically controls and distributes air entering the main rooms (bedrooms, living-rooms) according to the relative humidity in each room.

DESCRIPTION

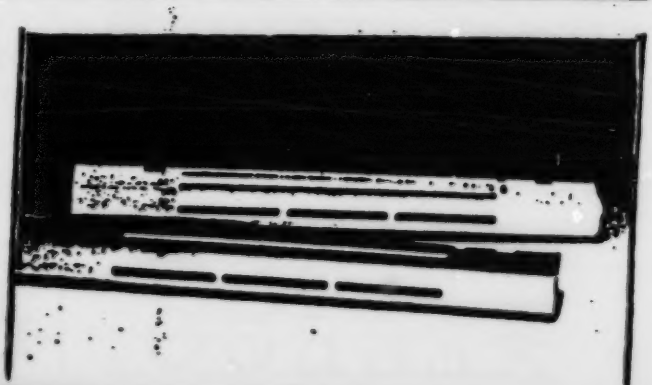
The AERECO relative humidity sensor is composed of 8 nylon strips, each with the same mechanical characteristics, assembled by a simple and reliable AERECO process.
The sensor's role is to detect any variation in relative humidity in the ambient air, mainly generated by the occupants, thanks to the intrinsic elongation property of nylon.
The information received by the sensor is then passed on to a mechanical system consisting of a single mobile shutter for the EMH unit and 2 mobile shutters for the EAH unit. In this manner, the air inlets automatically control the incoming airflow.
The size of the openings of the EMH and EAH units varies from 5 cm^2 to 30 cm^2, which - when below 10 Pa - in turn modifies the airflow from 5 m^3/h to 30 m^3/h (3 CFM ... 18 CFM).

CHARACTERISTICS AND SETTINGS

The AERECO EMH and EAH units have various settings in order to adapt them to different types of dwellings, climatic conditions and occupant life-styles.
The system is pre-programmed for two ventilation ranges, the first going from 23 % to 58 % relative humidity ("+"), the second from 35 % to 70 % (".") The "+" or "." settings are placed behind the front covering cap and are determined as follows:

setting	thermal bridge	climate
"." (35 % - 70 %)	small	temperate
"+" (23 % - 58 %)	wide	cold

Note: The whole AERECO ventilation system must operate throughout on the same relative humidity range. It is important to make sure that air inlet (EMH and EAH) and extraction outlets (BNG) are positioned the same settings.



"-" SETTING

During the winter time, when the temperature is 0°C, the relative humidity of the dwelling is very low (ie.30 %). When someone comes into a room, the relative humidity increases up to 35 % (5 points offset).

- Is the air inlet out of the operating range ?
- Will the room be more ventilated than the others ?

In fact, the humidity sensor detects your presence and the AERECO humidity controlled system ventilates the room in a proper way. Why ?

The AERECO system is designed to work in such conditions, the air inlet is adaptable.

The location of the air inlet allows the sensor's temperature to be lower than the temperature of the room. The sensor's temperature is related to the inside as well as the outside temperatures.

The sensor's temperature meets the following relation :

Temp. sensor = Temp.in −0.25 (Temp.in - Temp. out.)

The relative humidity of the sensor is then higher than the relative humidity of the room.

For example :

When the temperature of the room is 20°C and the outside temperature is 0°C, then the sensor's temperature is 17,5°C.

For this example the humidity variations will be :

Without occupant sensor's RH = 35 %
With occupants sensor's RH = 47 %

From the sensor side, the presence of a person increases the relative humidity by 8 points. The phenomenom is amplified and automatically brought into the humidity controlled range of the air inlet (35 % - 70 %).

"+" SETTING

The two ranges of humidity are (23 % - 58 % and 35 % - 70 %), both working the same way.

For examples :

- The outside temperature is − 10°C
- The inside temperature is + 20°C
- The inside relative humidity is 18 % (without occupant), and 23 % (with occupants).

According to these data :

- The sensor's temperature is 12,5°C
- The sensor's relative humidity is 30 % (without occupant), and 39 % (with occupants).

The phenomen is amplified and automatically brought into the humidity controlled range of the air inlet (23 % - 58 %). The AERECO system detects the occupants and adjusts itself to the local environment.

ACOUSTIC CARACTERISTICS

The ventilation noise is less than 25 DbA when pressure is less than 20 Pa.

	Mounting space	Weight	Unit size
EMH	240 × 15 mm 9"$_{1/2}$ × 3/5"	200 g	400 × 30 mm 15"$_{3/4}$ × 1"$_{1/4}$
EAH	255 × 24 mm 10" × 1"$_{3/4}$	250 g	312 × 65 mm 12"$_{3/4}$ × 2"$_{1/2}$

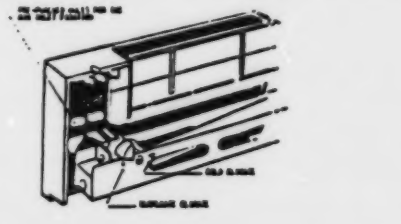
INSTALLATION AND MAINTENANCE

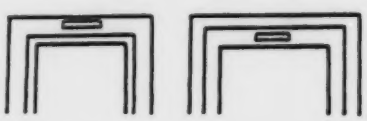
The EMH unit is specially designed to be fitted on window woodwork, and the EAH unit for the wall ducts.

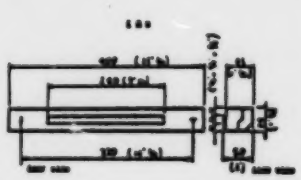
The only difference between the EMH and EAH units is their size, so they can both be used in wall of roof ducts or on window woodwork.

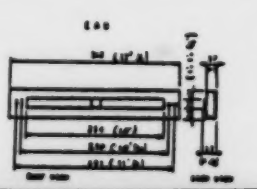
Optimal ventilation is obtained when air circulates throughout the room. The air inlets should be installed with this in mind, as well as the occupants' needs and furniture arrangement :

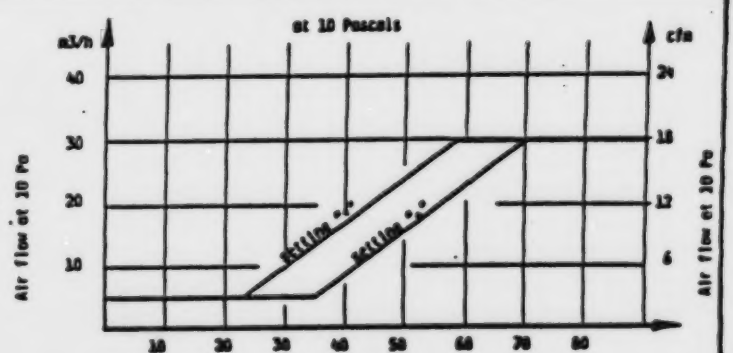
Air inlets do not need any maintenance.

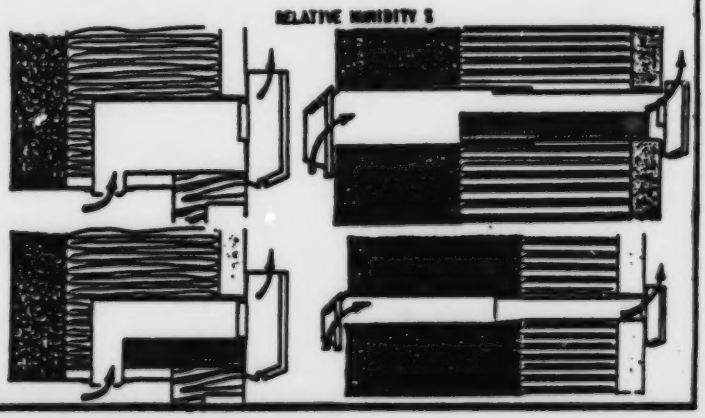












AERECO

APPENDIX D: MANUFACTURER'S RESPONSE

Modification proposed by CAN-AERECO VENTILATION INC.

The modifications proposed by CAN-AERECO promote to the reader the interpretation of the manufacturer and should give to the reader complimentary and useful information on the concept behind the product, further crucial data on the HCAI and ascertain some limits to the interpretation of the curves.

AERECO's proposition of modifications is divided in three parts:

I- To be inserted

II- To be modified

III- To be omitted

To illustrate the fact that AERECO HCAI amplify small changes in humidity, and to comfirm that the reading of the opening of the HCAI shows more visible correlation with occupancy than does humidity, it is possible to look at figure 17. In figure 17, the level of relative humidity rises by 10 points and the air inlet opening rises from 30% to 80%. It should be noted that the peak of CO2 at 1250 ppm in the master bedroom means that the air change rate in that bedroom was eleven litre per second (11 l/s).

However, such correlation between CO2 and the HCAI opening may not appear at all times on curves as the precited factors may interfere with the reading.
In fact, air inlets are not the only openings to outdoors; there are unintentionnal openings such as cracks and leaks. Part of the total air renewal of the room may pass through cracks and can reduce the level of humidity without demanding further opening of the air inlet. The conjunction of the UELA and the Delta P determines the airflow passing through the air inlet (1.7 l/s) and through the UELA (9.3 l/s).

The comments of CAN-AERECO VENTILATION INC. included in this report will detail information on item 0).

Page 32: After " RECOMMENDATIONS "

" COMMENTS OF CAN-AERECO VENTILATION INC. "

1-INTRODUCTION

2-IMPORTANCE OF A PASSIVE AIR INLET.

3-IMPORTANCE OF INSTALLING A PAI IN EVERY LIVING AREA OF A HOUSE.

4-IMPORTANCE OF BASING THE VENTILATION RATE ON A POLLUTANT.

5-PRE-DETECTION AND AMPLIFICATION FUNCTION OF AERECO HCAI.

6-CONCLUSION

2-IMPORTANCE OF A PASSIVE AIR INLET

Most passive air inlets (PAI) due to their aerolic profile, are less resistant to air movement than typical wall leaks or cracks. For the same Equivalent Leakage Area (E.L.A.) and the same pressure difference (Delta P), the PAI allows more fresh air to enter a room than a crack (i.e. 34% more at -4 Pa). In other words, for a same Delta P the opening of a leak has to be 34% bigger than the opening of a PAI to allow the same amount of air.
It should be pointed out also that this ratio changes with the delta P as shown in the following chart:

Ri ratio shows how much wider the opening of a crack has to be compared with an opening of a PAI, to ensure the same airflow:

DATA

Ratio = [(Delta P^ .5) - (Delta P^ .82)] / (Delta P^ .82)
Delta P : Deca Pa
Delta P exponent read at Morewood : .82
Delta P exponent of AERECO HCAI : .5

Delta P (Pa)	-1	-2	-3	-4	-5	-6	-7
Ri ratio	109%	67%	47%	34%	25%	18%	12%

Example: Delta P : -1 Pa
Opening PAI : 30 cm2

The opening of the crack has to be 62.7 cm2 (more than twice the PAI opening) to ensure similar airflow.

The leakier the house, the lower the Delta P, the higher Ri and the more significant the use of PAIs (109% at -1Pa).

The tighter the house, the higher the Delta P and the lower Ri. However the decreasing absolute value of the UELA reaffirms the importance of PAIs.

Whatever the airtightness of a house the opening of PAIs is significant to ensure correct distribution of supply air.

3-IMPORTANCE OF INSTALLING A PAI IN EVERY LIVING AREA OF A HOUSE

The value of the E.L.A. of a house and the repartition of that E.L.A. in every room is not easy to apply to the totality of new home constructions of CANADA, as it requires specific tests and equipment (Blower door and tracer gas tests).
Statistically, it is more than probable that every Cat A room will not have the same amount of unintentional ELA (random repartition).

If the ventilation relies only on the cracks and other leaks to bring fresh air in, rooms may have improper airflows. The same house equipped with PAIs will have adequate airflows at all times.

(For example: if the house's E.L.A. is 300 cm2 and the PAI is 30cm2 then the air going through the PAI is 11 CFM at 4 Pa.)

PAIs ACT AS A BACK UP OF THE UNINTENTIONAL ELA OF EACH ROOM, THAT IS WHY IT IS IMPORTANT TO INSTALL PAIs IN EVERY ROOM. This back up function becomes even more crucial when the UELA fluctuates over time, as the owner may renovate and/or weatherstrip his/her house.

It is not reasonable to rely only on the Unintentional Equivalent Leakage Area to ensure proper supply of fresh air in every room. Installing PAIs ensure proper air distribution.

4-IMPORTANCE OF BASING THE VENTILATION RATE ON A POLLUTANT

Using a given pollutant to operate a PAI offers several advantages:

TO ENSURE PROPER AMOUNT OF RENEWED AIR BY AUTOMATICALLY COMPENSATING THE UELA.

Low concentration of a pollutant means that the emission is weak or the UELA of the considered room is enough to ensure proper airflows by itself. In that case a controlled PAI may reduce its opening.

On the other hand, high concentration of a given pollutant may mean that the emission is strong or the UELA of the considered room is not enough to ensure proper airflows by itself. In that case a controlled PAI may increase its opening.

The same principle is used when using a tracer gas test to determine the level of air change rate of a room: the decrease of the concentration versus time indicates the renewal of fresh air.

TO OPTIMIZE AIR SUPPLY AND TO PROMOTE DIRECT ENERGY SAVINGS

Sensing when, where and how much air is required promotes direct energy savings to the occupant. The ventilation rate is continuously adapted to the needs so is the cost due to ventilation heat loss.

Pollutant-controlled PAIs continuously meet the needs for ventilation of occupants.

CHOOSING A REFERENCE POLLUTANT

When it comes to choosing a reference pollutant, humidity and carbon dioxide show different interesting characteristics:

CARBON DIOXIDE

CO2 shows very dynamic responses to changes in occupancy. Maintaining CO2 levels under a certain limit, see Health and Welfare Canadian guidelines for indoor air quality, ensures safety for occupants.

However, taking carbon dioxide as a reference may not be sufficient, and several major disorders can occur. The following points show some of them:

- Possible dampness of the air causes moisture damage to the house.

- Possible dryness of the air deteriorates indoor air quality and causes discomfort and may cause respiratory problems.
Excessive amount of airflow required to keep CO2 levels under the ASHRAE threshold of 1000 ppm will mean extreme dryness of the air during our Canadian winters and would require modifying the CSA F326 standard that does not meet such a requirement.

- Finally, the costs of such ventilation systems that required a sensor per room to be efficient, would have to fit the market place. At the present time the cost of reliable CO2 sensors is preventing the manufacturing of such ventilation systems.

It could be one of these points or their accumulation that makes officials (EMR, CMHC, NRC, CHBA...), the industry (manufacturer of bathroom fans, Air to air heat exchangers, contractors...), homeowners, promote, manufacture and use humidity sensors.

HUMIDITY

Relative humidity appears as a pertinent indicator for different reasons:

Excessive humidity is a potential hazard to the structure of the house. Moisture damage is mould, mildew, rotten wood structure and insulation.

Humidity is a major index of comfort and air quality. Unlike CO2, humidity directly affects the occupant. Using humidity as a reference for setting the ventilation rate, allows the occupants to live within a comfortable hygrometric environment (see ASHRAE recommendation for "best humidity ranges for health"). It should be noted that installation of AERECO humidity-controlled ventilation has greatly eased the occupant's asthma problem in the Carleton Place house.

The AERECO system is proportional to humidity, it uses the dehumidification effect of outdoor air to dry indoor air, and uses indoor water vapour emission to control indoor humidity. As a result, the indoor relative humidity remains within a comfortable range.

5-PRE-DETECTION AND AMPLIFICATION FUNCTION OF AERECO HCAI

AERECO HCAI uses two effects to vary airflow according to occupancy called pre-detection and amplification. These two effects are necessary to compensate for the fact that basing the changes of ventilation rate on humidity, minimizes necessarily its amplitude.

PRE-DETECTION:

The humidity sensor that consists of eight nylon strips is located close enough to the outside stream of fresh air to have the more thermal effect possible without creating any restriction to the incoming airflow. In other words, the HCAI sensor temperature is different than the room temperature.

Temp. sensor = Temp. in - .25 (Temp.in - Temp.out)

Example:
If Temp.out = - 10 Celsius, Temp.in = + 20 Celsius,
then Temp.sensor = 12.5 Celsius (7.5 Celsius less than room temperature).

Now if the relative humidity (RH) of the room is 18% without occupants, the RH read by the sensor is higher than the RH of the room 30%. This effect allows AERECO HCAI to detect room RH that is inferior to its lower factory "+" setting (23% to 58%). This effect operates with all combinations of room temperature, outdoor temperature, and room relative humidity.

Important: the absolute relative humidity remains the same and is homogenous in every part of the room.

AMPLIFICATION:

The amplification effect is based on the hygrometric diagram of " MOLLIER " that shows that the correlation between temperature and relative humidity is NOT LINEAR.

Taking the same data as in the previous example, can show what happens when occupants enter that room. People emit water vapour and the room RH changes for example from 18% RH to 23% RH, five (5) points of RH. The sensor's relative humidity will vary from eight (8) points of RH.

The PRE-DETECTION and the AMPLIFICATION effect of the AERECO HCAI reestablishes adequate amplitude due to change and ensures correct operation of the HCAI.

6-CONCLUSION

The use of PAI in every room of a house is far to be negligeable to ensure proper distribution of supply air. Also taking humidity as a reference to change the ventilation rate, versus any other pollutant such as CO2, ensures protection of the building structure as well as a healthy and comfortable indoor environment at all times.

II-To be modified

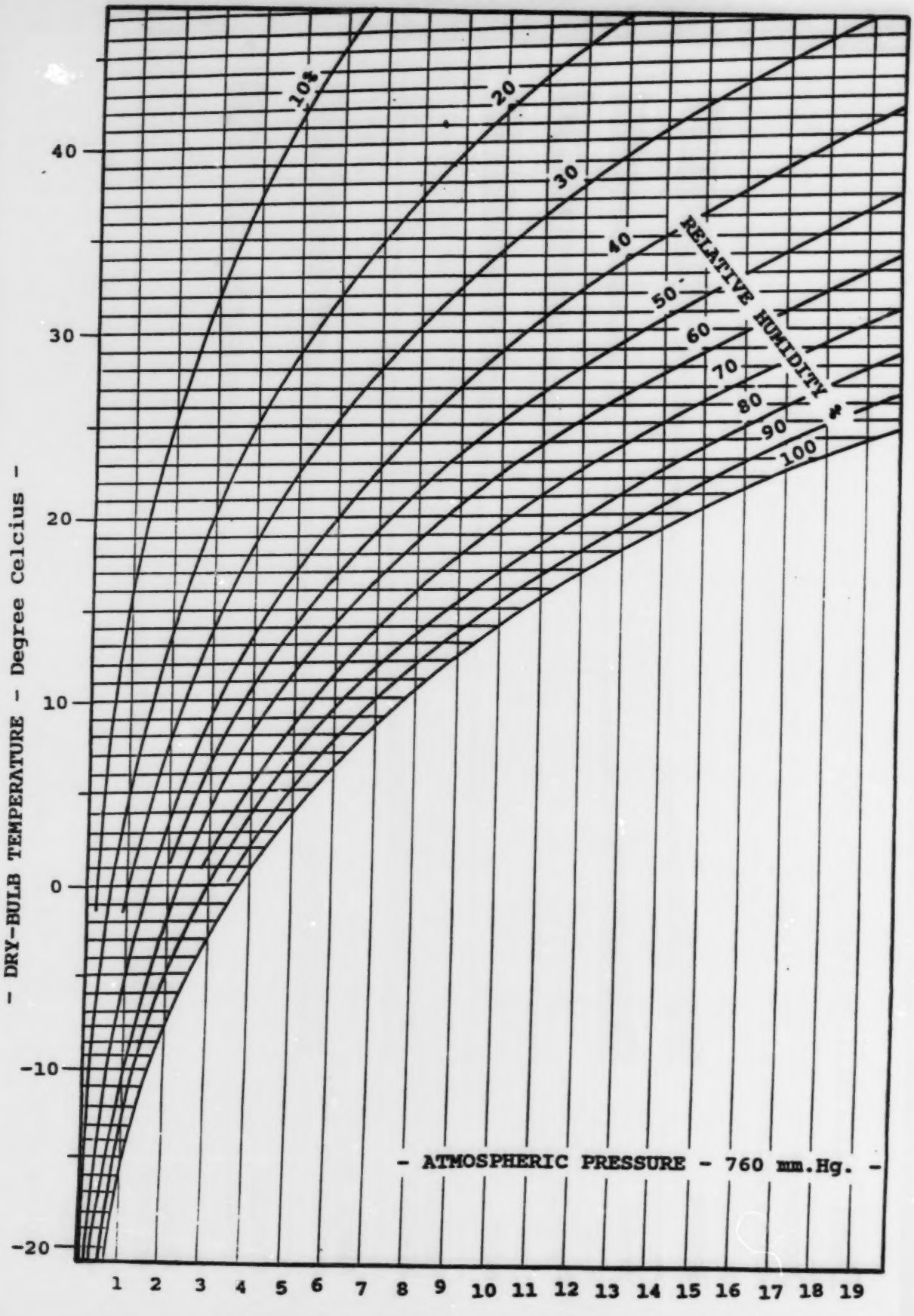
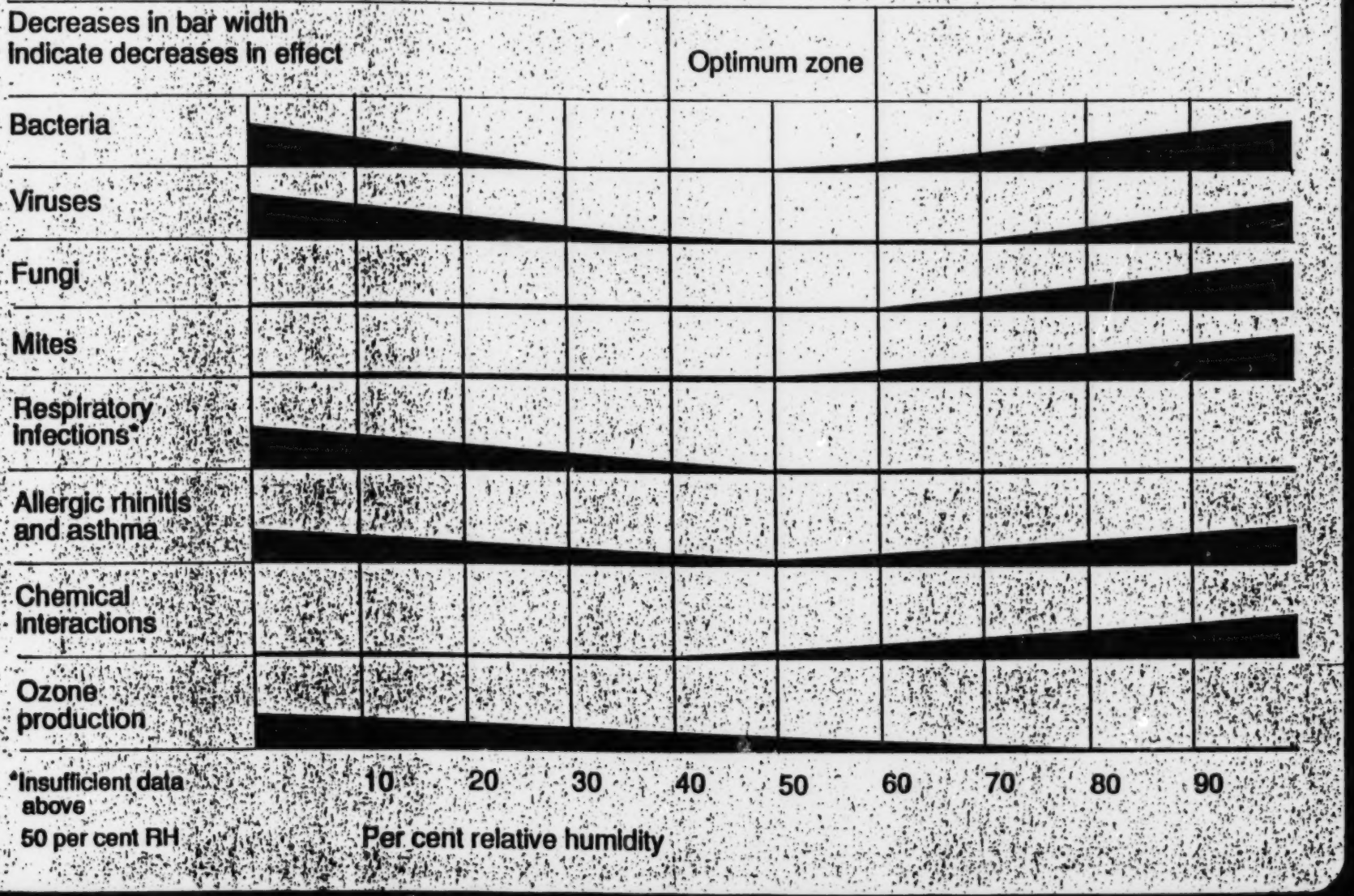
When "ventilation requirement" is in the text, add the reference: F326 ventilation requirement, ASHRAE ventilation requirements or other.

Page 1: Replace 30 000 by 135 000
Page 2: Replace 30 000 by 135 000
Page 6: Replace 30 cfm by maximum airflow

From page 14 to 31 all comments have to take into account item 0 and " Comments of CAN-AERECO Ventilation Inc. about the report on the monitoring".

III- To be omitted:
Discussion (item 1)

PSYCHROMETRIC DIAGRAM



Best humidity ranges for health